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FIELD SURVEILLANCE AND ENFORCEMENT GUIDE FOR PRIMARY METALLURGICAL INDUSTRIES

Engineering-Science, Incorporated

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This enforcement guide was published in anticipation of the problems which state local and Federal air pollution control officials may encounter in reviewing and understanding several primary metallurgical operations as they affect emissions to the atmosphere. It focuses on the primary metallurgical industry and includes a process description, a discussion of emission sources, typical control devices, stack gas and process monitoring instrumentation, and Inspectors Worksheets for operations in the iron and steel, aluminum, copper, lead, and zinc industries. All major operations in each of those industries were analyzed including an enforcement procedure for the storage and handling of raw materials. Upset conditions and abnormal operating circumstances were examined in relation to their role in air pollution. All major pollutants from these five industrial categories were examined. Generally the pollutant of most concern was particulate matter. Sulfur oxides and fluorides are unique to specific metals operations and were discussed accordingly. The manual includes sections on the inspection of pertinent air pollution control devices.

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Furnaces
Smelting
Coking
Casting
Roasting
Processing
Air pollution control equipment

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Enforcement guide
Air pollution detection

17c. COSATI Field/Group 13B, 11F

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ABSTRACT

This manual covers a step-wise enforcement procedure intended for use by state and local air pollution control agencies. This manual focuses on the primary metallurgical industry and includes a process description, a discussion of emission sources, typical control devices, stack gas and process monitoring instrumentation, and Inspectors Worksheets for operations in the iron and steel, aluminum, copper, lead, and zinc industries. All major operations in each of those industries were analyzed including an enforcement procedure for the storage and handling of raw materials. Upset conditions and abnormal operating circumstances were examined in relation to their role in air pollution.

All major pollutants from these five industrial catagories were examined. Generally the pollutant of most concern was particulate matter. Sulfur oxides and fluorides are unique to specific metals operations and were discussed accordingly. The manual includes sections on the inspection of pertinent air pollution control devices.

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Throughout the project, assistance was obtained from several trade associations, large corporations, and state agencies. These included: the Aluminum Association, the American Mining Congress, the Department of Interior, U. S. Steel, Bethlehem Steel, Kaiser Steel, Alcoa, Kaiser Aluminum and Chemical, Intalco, Eastalco, New Jersey Zinc, and others. Visits to these offices and plants provided an additional insight into the current technology of air pollution control in these various industries. The state air pollution control agencies of Maryland, Washington, and California also provided valuable information which helped make this project a success.

The principal investigator for Engineering-Science, Inc. was M. Dean High; Michael E. Lukey was Project Manager. Other staff members contributing to this project included: J. Kenneth Allison, Terrence A. Li Puma, and Mark L. Mercer. Mr. Robert A. Herrick and Stanley Berger of General Environments and Mr. Charles A. Licht of Charles Licht Engineering Associates also contributed to the manual.

FOREWORD

From time to time it will become necessary for air pollution control officials to make plant visits to the primary metals industries to assure that emission levels from these operations comply with existing air pollution regulations.

This Enforcement Guide was published in anticipation of the problems which state, local and Federal air pollution control officials may encounter in reviewing and understanding several primary metallurgical operations as they affect emissions to the atmosphere. As the name of this manual indicates, it is intended to serve as a fundamental reference on air pollution emissions from five different primary metal process industries: iron and steel production, aluminum reduction, and copper, lead, and zinc smelting. The manual has been designed to: (a) provide a process description which illustrates basic operating principles and variations, (b) discuss the significant operating variables which affect air pollution emissions, and (c) provide a stepwise approach which an enforcement official should follow when inspecting a primary metallurgical source.

This manual was prepared under contract with the U. S. Environmental Protection Agency, Office of Air Programs, Program Guideline and Information Branch, currently located at Research Triangle Park, N.C. 27711. The project was initiated on August 17, 1972 and scheduled to last 7 months. A portion of the task involving the iron and steel industry was subcontracted to General Environments Corp. Springfield, Va. Early in the Study it was deemed vital that plant visits would provide a first-hand understanding of the field activities of an enforcement official.

Permission was requested to visit metallurgical operations at selected nationwide locations and general cooperation was received from industry. Some plant officials showed some reluctance to participate in the engineering, whereas other officials did participate, but remained anonymous. Visits to state agencies provided invaluable guides with respect to the structure of this manual.

Generally the pollutant of most concern (on the basis of mass emission rate) is particulate matter. Sulfur oxides and fluorides are unique to certain metals operations yet particulates emanate from nearly every operation in the primary metals industry. Each section (Chapter) includes a discussion of the process, operating variables, and the procedure that should be followed when inspecting a site. It is not intended that this manual should be a substitute for source testing in determining compliance, nor is it anticipated that the enforcement official's Field Data File would take the place of an air pollution permit system. This study examines the type of air pollution regulations which exist for the industries and defines the stepwise approach that could be used to establish compliance/non-compliance on a routine schedule. In many cases the pollutant emission rate is a function of feed ore composition, e.g., sinter plant sulfur dioxide emissions. For those processes, a simple calculation procedure is described to determine emissions based on process weight by obtaining an assay of the raw ore for sulfur content. A similar type of calculated emission rate for particulate matter from these sources is not plausible. At this stage in controlling air pollution, almost all particulate sources will be controlled to some degree. For this reason a complete section was devoted to air pollution control devices (Part VI) in which is discussed the operating principles and operating variables of air pollution abatement systems. In order to assess stack gas particulate levels, invariably some measuring device will have to be used. Consequently, this manual includes a section (Part VII) on the test equipment and method that could be used to measure particulate emissions, as well as sulfur dioxide, fluorides, hydrocarbons, and exhaust gas parameters in a manner not consistent with the EPA testing procedure, but adequate to obtain an estimate using a simplistic/quick method approach.

Since many of the operations inherent in the primary metals industry already have air pollution abatement devices installed, the task of enforcement becomes (among others) one of properly maintaining and operating control equipment at or near design specification. Furthermore, for many of the larger metals operations, stack tests will be made on the abatement equipment and the data will be submitted to control agencies. Based on the emission results, plant operators may have to provide additional or better controlled systems. For the metals operations it is likely that "upsets" in the operation can cause higher emissions, exceeding the design of control systems, and result in neighborhood complaints to the agency. It is anticipated that the enforcement official will be called upon immediately to respond to these complaints. For this reason this manual examines several factors that would demonstrate a properly maintained control device (such as spark rate, pressure drop, etc.) and factors that cause an upset condition, including what can and should be done to enable a return to normal.

This manual was prepared by Engineering-Science, Inc., Washington, D.C. offices. The EPA/OAP project officers were Geoffrey Stevens and Bruce Hogarth.

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LIST OF ABBREVIATIONS

Common Units

acf	actual cubic feet
acf/hr or acfh	actual cubic feet per hour
acfm	actual cubic feet per minute
atm	atmospheres
bbl	barrels
bbl/day	barrels per day
Btu	British thermal units
Btu/gal	British thermal units per gallon
Btu/hr	British thermal units per hour
Btu/ton	British thermal units per ton
°C	degrees Centigrade
cf	cubic feet
cfm	cubic feet per minute
cfm/ft^2	cubic feet per minute per square foot
day	days
EA	excess air
°F	degrees Fahrenheit
fps	feet per second
ft	feet
g	grams
gal.	gallons
gpd	gallons per day
gpm	gallons per minute
gr/cf	grains per cubic foot
gr/scf	grains per standard cubic foot
hp	horsepower
in.	inches
in. Hg	inches of mercury
in. H_2O	inches of water
in. wg	inches water gauge
j	joules

Common Units (Continued)

kcal	kilo calories
kv	kilovolts
kw	kilowatts
kwh	kilowatt hours
lb	pounds
long ton	2,240 pounds
m	meters
ma	milliampere
mcf	millions cubic feet
mps	meters per second
mwh	megawatt hours
ohm-cm	ohm centimeter
psi	pounds per square inch
°R	degrees Rankine
scf	standard cubic feet
scfh or scf/hr	standard cubic feet per hour
scfm	standard cubic feet per minute
spm	sparks per minute
sq ft	square feet
ton or short ton	2,000 pounds
tons/day	tons per day
wg	water gauge
μ	microns
μg	micrograms
$\mu g/m^3$	micrograms per cubic meter
10^6 Btu	million British thermal units
%	percent

Chemical Elements

Al	aluminum
As	arsenic
Ag	silver
Au	gold

Chemical Elements (Continued)

Ca	calcium
Cd	cadmium
Co	cobalt
Cu	copper
Fe	iron
Hg	mercury
Mg	magnesium
N	nitrogen
Na	sodium
Ni	nickel
O	oxygen
Pb	lead
S	sulfur
Sb	antimony
Sn	tin
Zn	zinc

Common Symbols

A	area
C	concentration
d	diameter
m	molecular weight
M	mass, weight
p	pressure
Q	flow rate
R	gas constant
T	temperature
u	speed
V	volume
ρ	density

Subscripts

s	standard conditions; 70°F and 29.92 in. Hg
w	water vapor

PART I

IRON AND STEEL INDUSTRY

Steel is the most widely used single industrial material for the manufacture of transportation equipment, construction materials, durable goods, defense hardware and metal containers. The U.S. industry is the world's largest producer of steel, accounting for 20 percent of the total world production.

The steel industry in this country is highly concentrated. Four companies account for more than 50 percent of production and the eight largest companies produce 75 percent of the steel output. The major steel markets are located in the Midwest and Northeast and five states in these regions account for almost 70 percent of the raw steel production.

The making of steel involves steps ranging from the mining of raw materials from the ground to the shaping and treating of finished products. The basic raw materials needed for the production of steel are iron ore, coke and limestone. Ore is received at the steel plant in bulk or in some cases processed into pellet form, but bulk ore is commonly crushed and sintered into lumps. The use of pelletized or sintered ore facilitates furnace operation.

Coke is produced at the plant site by heating coal in the absence of air. It is the basic source of heat in the blast furnace and provides the carbon which acts as the reducing agent. The limestone is used in the same form as mined except for crushing and provides a means for removing impurities from the iron being made.

The blast furnace smelts ore to produce pig iron. Ore, coke and limestone are combined in the blast furnace and hot air is injected, igniting the coke and providing oxygen for combustion. The impurities are removed separately from the iron in the form of slag.

The steel making furnaces that convert pig iron, scrap and alloys into steel of the desired composition are open hearth, basic oxygen and electric. The open hearth furnace is relatively slow. The amount of raw steel produced by this method has decreased from 84 percent in 1962 to 37 percent in 1970. The basic oxygen furnace converts molten pig iron and scrap to steel by blowing large quantities of oxygen into the charge. This process has a high production rate and is replacing the open hearth process. Basic oxygen furnace production has increased from 7 percent of the raw steel produced in 1962 to 48 percent in 1970. Electric furnaces are generally charged with cold scrap and alloys to produce a variety of steels. Heat is produced by electricity flowing through the metal. Steel production by electric furnaces has increased from 9 percent in 1962 to 15 percent in 1970.

Primary shaping of the molten steel is most commonly accomplished by pouring ingot molds. After solidifying, the steel ingot is reheated and rolled to a convenient size for further processing. These shapes, depending on the dimensions, are called billets, blooms or slabs. A newer method for shaping the steel is the continuous casting process. Molten steel is continuously formed into shapes similar to those produced by primary rolling of ingots.

The primary shape is reduced to final dimensions by a series of rolling operations. The steel can then be treated by a variety of surface coatings or conditioning processes depending on the particular product need.

There are about 200 steel producing companies (Table I-1) but only 25 are integrated from the blast furnace through the rolling mills. There are 61 companies that produce raw steel from scrap only. The remainder process semi-finished steel into finished products.

TABLE I-1

STEEL COMPANIES

Company	Coke Ovens	Blast Furnaces	Steelmaking Furnaces		
			Open Hearth	Electric	Basic Oxygen Process
Alan Wood Steel Co.	x	x			x
Allegheny Ludlum Steel Corp.				x	
Allison Steel Mfg. Co.				x	
American Compressed Steel Corp.				x	
Armco Steel Corp.	x	x	x	x	x
National Supply Division				x	
Atlantic Steel Co.				x	
Babcock & Wilcox Co.				x	
Baldwin-Lima-Hamilton Corp:					
Standard Steel Div.				x	
Bethlehem Steel Corp.	x	x	x	x	x
Border Steel Rolling Mills, Inc.				x	
Borg-Warner Corp:					
Calumet Steel				x	
Ingersoll Steel Div.				x	
Braeburn Alloy Steel Div.				x	
Cabot Corp.				x	
Cameron Iron Works, Inc.				x	
Carpenter Technology Corp.				x	
Ceco Corp:					
Lemont Manufacturing Corp.				x	
Milton Manufacturing Co.				x	
Southern Electric Steel Co.				x	

TABLE I-1

STEEL COMPANIES (Continued)

Company	Coke Ovens	Blast Furnaces	Steelmaking Furnaces		
			Open Hearth	Electric	Basic Oxygen Process
C F & I Steel Corp.	x	x	x	x	x
Columbia Tool Steel Co.				x	
Continental Steel Corp.				x	
Copperweld Steel Co.				x	
Crucible Inc.	x	x		x	x
Cyclops Corp:					
Empire Reeves Steel Div.			x	x	
Universal-Cyclops Spec. Steel Div.				x	
Detroit Steel Corp.	x	x	x		
Eastern Stainless Steel Corp.				x	
Edgewater Corp.				x	
Latrobe Forge & Spring, Inc.			x		
Etiwanda Steel Producers, Inc.				x	
Florida Steel Corp.				x	
Ford Motor Co.	x	x			x
Georgetown Steel Corp.				x	
Granite City Steel Co.	x	x			x
Harper Co., H. M.				x	
Harrisburg Steel Co.:					
Division Harsco Corp.			x		
Hawaiian Western Steel Ltd.				x	
Heppenstall Co.			x		
Midvale-Heppenstall Co.				x	
Inland Steel Co.	x	x	x	x	x
Intercoastal Steel Corp.				x	
Interlake Inc.	x	x	x	x	x
International Harvester Co.:					
Wisconsin Steel Div.	x	x			x
Jessop Steel Co.				x	
Green River Steel Corp.				x	
Jones & Laughlin Steel Corp.	x	x	x	x	x
Jones & McKnight Corp.				x	
Jorgensen Co., Earle M.				x	
Joslyn Stainless Steels Div.				x	
Judson Steel Corp.				x	
Kaiser Steel Corp.	x	x	x		x

TABLE I-1

STEEL COMPANIES (Continued)

Company	Coke Ovens	Blast Furnaces	Steelmaking Furnaces		
			Open Hearth	Electric	Basic Oxygen Process
Kentucky Electric Steel Co.				x	
Keystone Consolidated Ind., Inc.:					
Keystone Steel & Wire			x	x	
Laclede Steel Co.				x	
Latrobe Steel Co.				x	
Le Tourneau, Inc., R. G.				x	
Lone Star Steel Co.	x	x	x		
Lukens Steel Co.			x	x	
McLouth Steel Corp.		x		x	x
Mesta Machine Co.			x	x	
Mississippi Steel Div. of Magna Corp.				x	
National Forge Co.				x	
National Steel Corp.:					
Great Lakes Steel Div.	x	x	x	x	x
Hanna Furnace Corp.		x			
Weirton Steel Div.	x	x	x		x
Newport News Shipbuilding & Drydock Co.				x	
North Star Steel Co.				x	
Northwest Steel Rolling Mills, Inc.				x	
Northwestern Steel & Wire Co.				x	
Owen Electric Steel Co. of South Carolina				x	
Pacific States Steel Corp.			x		
Phoenix Steel Corp.			x	x	
Pollak Steel Co.				x	
Porter Co., Inc., H. K.:					
Connors Steel Div.				x	
Republic Steel Corp.	x	x	x	x	x
Finkl & Sons Co. A.				x	
Roblin Steel Co.				x	
Sharon Steel Corp.	x	x	x	x	x
Carpentertown Coal & Coke Co.	x				

TABLE I-1

STEEL COMPANIES (Continued)

Company	Coke Ovens	Blast Furnaces	Steelmaking Furnaces		
			Open Hearth	Electric	Basic Oxygen Process
Shenango Incorporated	x	x			
Simonds Steel Div. (Wallace-Murray Corp.)				x	
Soule Steel Co.				x	
Southwest Steel Rolling Mills				x	
Structural Metals, Inc.				x	
Tennessee Forging Steel Corp.				x	
Texas Steel Co.				x	
Timken Co.				x	
Tonawanda Iron Division, American Standard Inc.		x			
Union Electric Steel Corp.				x	
United States Pipe & Foundry Co.	x	x			
United States Steel Corp.	x	x	x	x	x
Vasco Metals Corp.				x	
Washburn Wire Co.				x	
Washington Steel Corp.				x	
Wheeling-Pittsburgh Steel Corp.	x	x	x		x
Woodward Co.:					
Woodward Iron Div.	x	x			
Youngstown Sheet and Tube Co.	x	x	x		x

1. PELLETIZING

Sulfur dixoide emissions are a function of the sulfur in the raw materials. Particulate emissions are a function of the original design and current condition of the dust collectors. To a minor extent, particulate emissions can be adversely affected by unsettled furnace operation but it is not likely that such operation would be allowed to continue for an extended period of time because of its adverse effect on product quality. Outloading can be a major source of fugitive dust.

1.1 Process Description

Pelletizing is the agglomeration of finely ground iron ore into a fairly uniform size ball-shape. Pelletizing plants are usually located at or near the mine site (see Table 1.1). The finished pellets are shipped to the steel plant for use directly in the blast furnace. Productivity of the blast furnace is increased when the charge is made up of high grade, uniform burden such as pellets as opposed to unsized raw ore. Fines generated from the crushing and grinding of high grade lump ore during sizing operations and beneficiated low grade ore are utilized to form pellets. The use of pellets is increasingly becoming a significant mode of operation in the iron and steel industry, as shown in Table 1.2.

Pellets are made by rolling fine iron ore mixed with a binder to form "green" pellets (about 3/8 inch to 1 inch in diameter) which are then heated. Bentonite, the usual clay binder, is the principal additive. Other additives such as soda ash, limestone, or dolomite are sometimes used to improve pellet strength. The most widely used devices for forming pellets are the balling drum and the disc pelletizer.

TABLE 1.1

IRON ORE PELLET PLANTS IN THE UNITED STATES

Company	Location	Annual Capacity (gross tons)
Bethlehem Steel Corporation		
Cornwall	Cornwall, Pennsylvania	700,000
Grace	Morgantown, Pennsylvania	1,500,000
The Cleveland-Cliffs Iron Company		
Empire Iron Mining Co.	Palmer, Michigan	3,200,000
Humboldt Mining Co.	Humboldt, Michigan	800,000
Marquette Iron Mining Co.	Eagle Mills, Michigan	800,000
Marquette Iron Mining Co.	Republic, Michigan	2,000,000
Pioneer Pellet Plant	Eagle Mills, Michigan	1,200,000
The Hanna Mining Company		
Butler Taconite	Nashwauk, Minnesota	2,000,000
Groveland	Iron Mountain, Michigan	2,100,000
National Steel Pellet Co.	Keewatin, Minnesota	2,100,000
Pilot Knob Pellet Co.	Ironton, Missouri	1,000,000
Inland Steel Company		
Jackson County Iron Co.	Black River Falls, Wisconsin	750,000
Kaiser Steel Corporation		
Eagle Mountain	Eagle Mountain, California	2,000,000
Meramee Mining Company		
Pea Ridge	Sullivan, Missouri	2,000,000
Oglebay Norton Company		
Eveleth Taconite Company	Eveleth, Minnesota	1,600,000
Pickands Mather & Co.		
Erie Mining Company	Hoyt Lakes, Minnesota	10,300,000
Reserve Mining Company		
E. W. Davis Works	Silver Bay, Minnesota	10,700,000
United States Steel Corporation		
Atlantic City Ore	Atlantic City, Wyoming	1,500,000
Minntac	Mountain Iron, Minnesota	4,500,000
	Total United States Annual Capacity	51,050,000

TABLE 1.2

PHYSICAL FORM OF IRON ORE CONSUMED IN THE UNITED STATES AND ESTIMATES TO 1980

Year	Lump Ore		Sinter Fines[a]		Pellets		Total	
	Millions of Tons	Percent	Millions of Tons	Percent	Millions of Tons	Percent	Millions of Tons	Percent
1960	62.0	54.1	41.5	36.3	11.0	9.6	114.5	100.0
1967	46.7	35.3	42.2	31.9	43.4	32.8	132.3	100.0
1975	31.7	20.0	46.0	29.0	80.8	51.0	158.5	100.0
1980	34.9	19.5	48.3	27.0	95.8	53.5	179.0	100.0

(a) Includes only iron-ore fines used for making sinter. For example, sinter production in 1967 was 51.6 million net tons but required only 42.2 million tons of iron-ore fines. The remainder was supplied as mill scale, dust, fluxes, and the like.

The disc has a greater possibility of adjustment and produces a more uniform pellet size which simplifies screening of the product, but the capacity of the disc is lower than the drum and generally requires closer control. In the pellet-forming process a small amount of pulverized coal may be added to the pellet mix or coated on the pellets to supply part of the heat required during the firing step. Oxidation of the pelletized magnetite (Fe_3O_4) concentrate to hematite (Fe_2O_3) may also supply a significant proportion of the process heat requirement.

The three most important pelletizing systems are the traveling-grate (updraft and/or downdraft) system, the shaft-furnace system, and the grate-kiln system. In the first method, green pellets coated in a balling drum with a fine layer of fuel are continuously fed to a traveling grate, Figure 1.1. The first few of the wind boxes below the grate are used to dry and preheat the moist pellets. After ignition of the bed, a downdraft of air is continued until all the fuel is consumed and substantially all the magnetite is oxidized to hematite, Figure 1.2. An updraft of air is then applied to cool the pellets. Fuel requirements are about 700,000 Btu per long ton of pellets with another 300,000 Btu obtained from the oxidation of magnetite. An advantage of this system is the close control that can be maintained over each step of the pellet-hardening process.

In the shaft-furnace system, Figure 1.3, the fuel is mixed inside the pellet rather than as a coating on the outside, as in the traveling-grate process. The green pellets are distributed at the top of the shaft furnace. As the pellets pass down through the furnace they are first dried and then heated to the pelletizing temperature of approximately 2,400°F in the top portion of the unit. From here down to the bottom of the furnace the pellets are cooled by an upward-rising stream of air. At the bottom of the shaft, the pellets are discharged through a chunk-breaker. Difficulty can arise if a uniform combustion zone is not maintained and hot spots develop. This will cause the pellets to fuse together into large masses and, in addition to discharge problems, a sudden shift of the pellets will produce heavy particulate emissions. Advantages of the shaft-furnace are simplicity of design and a high degree of heat recuperation. Fuel requirements are about 500,000 Btu per ton of pellets with a magnetite concentrate. The shaft furnace is unsuitable for hematites, primarily because of the "hanging" or sticking that results from the additional heat input that must be supplied in the hardening of hematite pellets.

The grate-kiln system, Figure 1.4 combines the advantages of the traveling grate with a rotary kiln. In this system the pellets are dried and preheated on a traveling grate and then hardened by high temperature

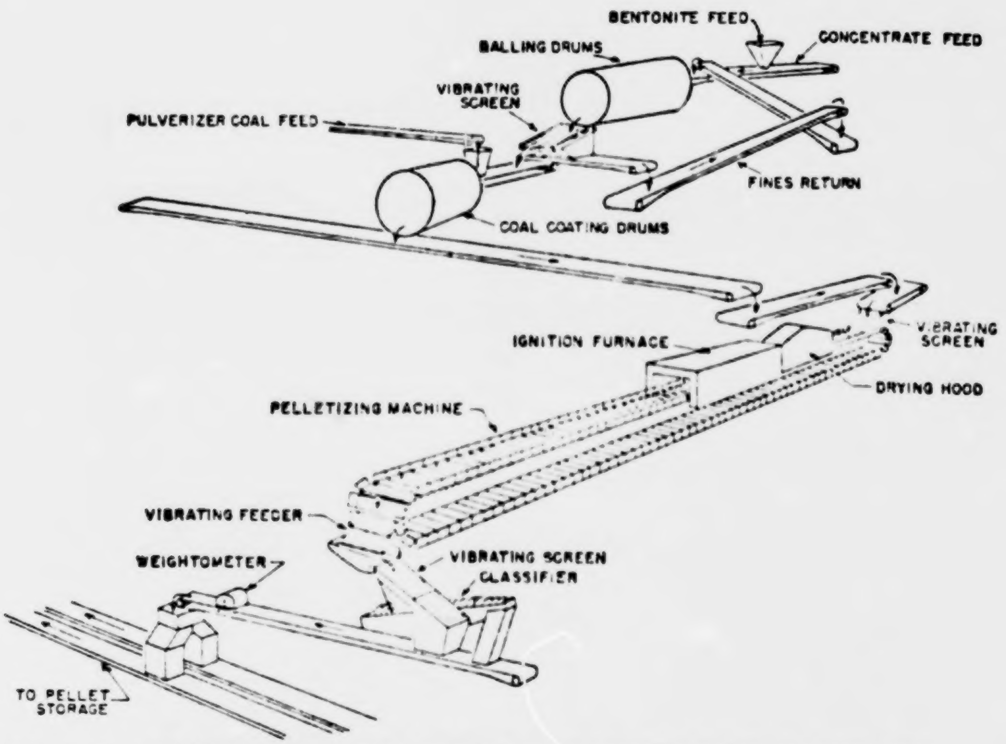

BENTONITE FEED
CONCENTRATE FEED
BALLING DRUMS
VIBRATING SCREEN
PULVERIZER COAL FEED
FINES RETURN
COAL COATING DRUMS
VIBRATING SCREEN
IGNITION FURNACE
DRYING HOOD
PELLETIZING MACHINE
VIBRATING FEEDER
WEIGHTOMETER
VIBRATING SCREEN CLASSIFIER
TO PELLET STORAGE

FIGURE 1.1 SIMPLIFIED FLOW DIAGRAM ILLUSTRATING PRINCIPLE OF THE PELLETIZING PROCESS USING THE TRAVELING GRATE METHOD

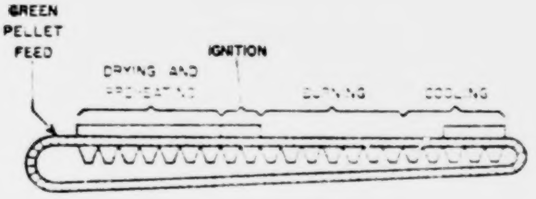

GREEN PELLET FEED
IGNITION
DRYING AND PREHEATING
BURNING
COOLING

FIGURE 1.2 SCHEMATIC DIAGRAM OF THE TRAVELING GRATE SYSTEM FOR PRODUCING PELLETS

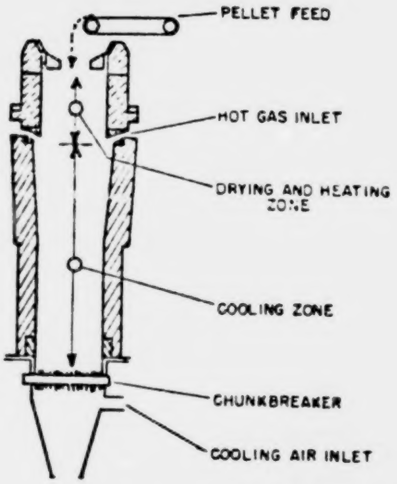

PELLET FEED
HOT GAS INLET
DRYING AND HEATING ZONE
COOLING ZONE
CHUNKBREAKER
COOLING AIR INLET

FIGURE 1.3 SCHEMATIC DIAGRAM OF THE SHAFT FURNACE SYSTEM FOR PRODUCING PELLETS

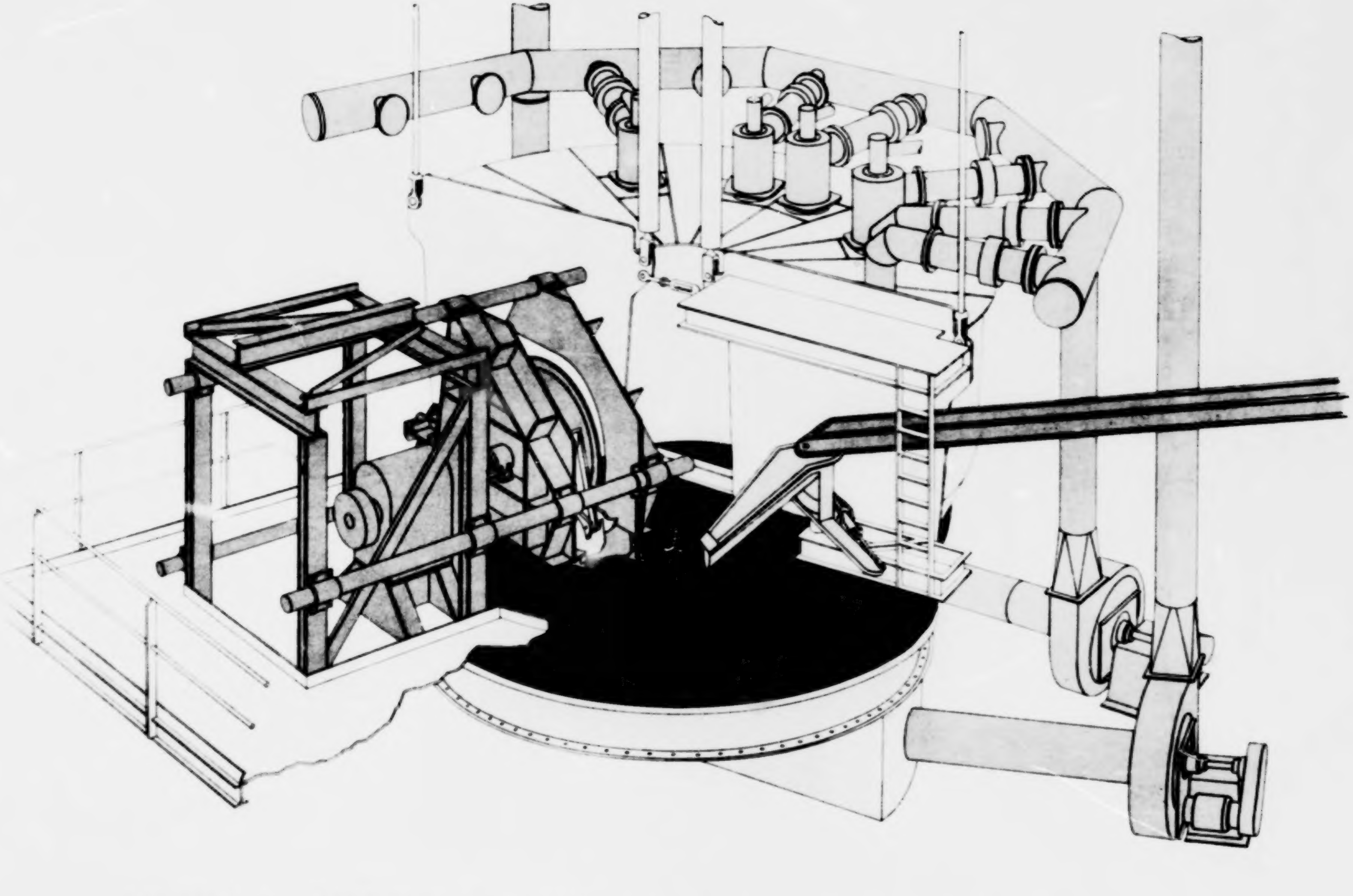


FIGURE 1.4 PILOT PLANT PELLETIZING MACHINE - CIRCULAR GRATE SYSTEM

heating in a rotary kiln. Hot gases discharged from the kiln are used in the downdraft drying and preheating section of the grate. No solid fuel is added to the pellets with this method. About 1 million Btu per ton of pellets is required and is generally supplied by fuel oil.

Ore concentrates received at the pelletizing plant are normally moist, thus dust generation during receiving is not a problem. Bentonite is received in covered hopper cars and is unloaded into special bins that meter the material into the pelletizing operation. Particulate emissions of magnetite, hematite, or bentonite are possible. Dusts produced in the materials handling portion of the plant are sometimes controlled by medium energy wet scrubbers and although finished pellets are strong and abrasion loss is low, a considerable amount of dust can be released during loading for shipment because of the very large amount of material being handled.

There is a possibility of some sulfur dioxide emissions during the firing operation. Sulfur is sometimes found in the ore concentrate in the form of pyrites and the amount of SO_2 formation would be proportional to the sulfur content of the ore. A small amount of sulfur might be in the pulverized coal but because of the small amount used the effect would be minimal. The iron and steel industry tries to keep the amount of sulfur-bearing ore to a minimum because some of the sulfur becomes sulfate ($SO_4^=$) in the pellets and this is undesirable in the steel making process.

1.2 Process Control Operation

The strength and hardness of finished pellets is maintained in order to minimize degradation by breakage and abrasion during handling. A check on these physical characteristics is conducted by exposing a control sample of pellets to compression and tumbling tests. In addition to the properties of the ore concentrate, pellet quality is affected by additives, balling method, firing technique and temperature, test procedure and size. Depending on these variables, pellet compressive strengths have been reported between 250 and 5,000 lbs. A commercially acceptable 1/4-inch pellet has a minimum strength as low as 300 lbs while it is 800 to 1,500 lbs for a 1-inch pellet. The tumbler test consists of a drum tumbler (ASTM D 294-50) operating at 25 rpm for 200 revolutions with 25 to 50 lbs of plus 3 mesh (3/8 inch) pellets. After screening the product, satisfactory commercial pellets should contain not more than 6 percent of minus 28 mesh fines and at least 85 percent of plus 3/8 inch size. It is also desired there be a minimum of broken pellets between these sizes. It is advantageous to the production of steel to use strong, hard, uniform pellets. Sub-standard pellets, i.e. those that tend to crumble and create dust, are inefficient for steel making.

Although materials flowing into the pelletizer are metered and monitored, the easiest check of the production rate is the pellet weightmeter at the end of the process. This record-keeping instrument is located near the transfer point where finished pellets are placed on the product conveyor belt.

Air flows in the firing and cooling sections of the pellitizing process are monitored with pressure gauges and recorders. A record is kept of the pressure drop and suction in the windbox which is located under the grate in both the grate-kiln and traveling-grate systems. In the shaft-furnace process, air flow into the furnace is recorded at both the hot gas inlet and the cool gas inlet. Individual shaft furnaces are commonly coupled to a single tall stack. Other plants utilize hoods over each furnace which direct the exhaust gas into multi-cyclones prior to release to the atmosphere.

For plant production record purposes major air volumes and static pressures are metered and continuously recorded. At shaft furnaces, for example, the volumetric air flow and the inlet static pressure of the combustion air supplied to the top of the furnace are recorded. Should the pellet bed hang up, the pressure would increase and/or the air flow would decrease. When the bridged mass of pellets breaks free an open channel could develop which would cause a sudden drop in pressure and/or increase in flow and would be evident on the charts. During this period particulate emissions increase because of the increased gas velocity through a small portion of the bed. A review of the charts would indicate whether the plant has had this sort of difficulties with any frequency over a given period of time.

The situation described previously where the gases are passing through a small section of the bed at high velocity is called a "blow" in a shaft furnace. A bad blow might throw red hot pellets as far as fifty feet onto the charging floor. Production rate and pellet quality are both adversely affected during operation of the furnace under blow conditions.

Typical emission controls consist of multiple small diameter cyclones for the capture of particulate matter from the process gas streams. There may be a manometer across the cell plate or between the upstream and downstream duct of these dust collection units.

Pellet dust is quite abrasive and the temperature of the gas streams can have excursions to over 1,000°F during upset conditions at the furnace. The major elements which would contribute to these collectors operating at less than design efficiency are abrasive wear and warpage, both of which cause short circuiting between the dirty and clean side of the collector. The pressure-drop/gas-volume relationship for multi-cyclones is not sensitive enough to record these problems until they develop to major proportions. An increase in visible emission intensity over a period of time would suggest this type of deterioration of the cyclones. The only certain way to identify the presence or absence of minor leakage of air at multi-cyclone dust collectors in a pellet plant is to visually inspect the unit. Furnace shut-downs are generally not scheduled more than 2 or 3 times a year, so cyclone inspection can not be a routine procedure.

1.3 Enforcement Procedure

Emissions from the pellet plant consist of sulfur dioxide and particulates. Air pollution abatement equipment is used at all plants to control particulate emissions.

The objective of pellet plant inspections is to establish compliance with the particulate and sulfur dioxide emission regulations. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,

4. Efficiency and adequacy of emission control equipment at current and design levels.

Both plant and emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to plant inspection. Production levels, feed weight rates and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

Make a visual inspection of the entire plant, tracing the material flow from raw material storage to finished pellet outloading. Look closely at conveyor belt transfer points for excessive amounts of dust formation. Loading of finished pellets into railroad cars or barges can be a major fugitive dust source. If wetting sprays are used to reduce dust emissions during material handling see that they are operating properly with sufficient volume and pressure.

Observe the collection hoods to see if they are properly located and that their capture velocities are adequate. If dust is escaping the hood it is an indication that the collection system is undersized, out of adjustment, or not located close enough to the point of emission. Check the general condition of the system looking for holes and leaks in the ducting due to wear, corrosion, and excessive fan vibration. These conditions contribute to inefficient operation of control equipment.

If shaft furnaces are being used for the pelletizing process, check the air flow and/or the pressure records to establish the frequency of upset conditions (blows). Ask the operator what happens during blow conditions.

Compare the operating levels of the control devices being used against design conditions. The procedures described in Part VI of this manual can be used to estimate emissions.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plume and, if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine point(s) of origin and require corrective action.

Of importance for the enforcement of air pollution emission regulations is the process weight. With the mass rate and sulfur content of the feed and product, SO_2 emissions can be estimated.

Compare these estimated emissions with allowable levels in the regulations. Take appropriate action.

2. RECEIVING, STORING AND HANDLING OF MATERIAL

Possible emissions will be particulate matter. Fugitive dust regulations will govern.

2.1 Process Description

Raw materials arrive at steel plants by water or rail with some minor amounts of materials arriving by truck. The raw materials are unloaded to open stockpiles, with the exception of a few materials such as lime which is shipped in closed hoppers or container cars and then transferred to enclosed hoppers without exposure to the atmosphere. Most of the materials received are in a presized condition; i.e. the crushing and sizing was already accomplished at the mine, quarry or pelletizing plant.

Transfer of the materials into and out of storage and to the processing centers creates a persistent dust problem, due to the fine material always associated with bulk handling of ore, coal and limestone.

Coal storage piles are susceptible to spontaneous combustion so they must be "turned over" from time to time.

2.2 Process Control Operation

Open stockpiles may reach a height of 100 feet and cover up to ten acres. Because stockpiles of raw materials are exposed to the weather and can be dusty, various techniques have been attempted to suppress dusting. These methods have ranged from simple wetting with water to spraying with special plastic materials. The large tonnages and available methods of material handling for stockpiling and reclaiming make it economically impractical to house or shroud the stockpiles.

Transfers from stockpiles usually are by means of overhead clambucket gantries to bottom-dump cars, or by endless conveyor belts for upward movement and gravity chutes for downward movement. Dust is generally created at each transfer point. Outdoor belts normally are covered but not enclosed and dusting can occur during windy weather. Emission of particulates to the atmosphere from materials in the building usually can be controlled and emission control at indoor transfer points is often controlled by cyclone dust collectors. Coal dust inside a building can be controlled at transfer points by the use of wetting agents and water sprays.

No record keeping is maintained by the steel industry on the amount of raw materials lost by dusting.

While methods of receiving, storing and handling of raw materials affect the amount of fugitive dust, the inherent dustiness of the materials and the meteorological conditions of the area are the most significant factors.

2.3 Enforcement Procedure

The following enforcement procedure describes general observations which can be made for the materials handling at steel plants. Due to the non-uniformity of the raw materials, the following general guides for this type of inspection are suggested:

1. Trace the flow of raw material from the time it arrives at the plant until it enters the process.
2. From a distance, observe the raw material and processed materials for dust clouds either from roadways, stock piles, transfer points, crushers or screening operations, slag dumping, plant construction activities, etc. These sources are generally not continuous emitters, but depend on the individual activity schedule.
3. Make records of the dusty areas for a close-up inspection. These observations should be made from beyond the plant perimeter on a hillside overlooking the entire complex, if possible for a period of several hours.
4. Observe the raw material stock piles when the wind is blowing and note any entrained dust.

5. Observe the material-moving methods at the stockpile.
6. If the material is brought in on bulk transporters, note any dust emissions during handling.
7. If cranes, belts, or bulldozers are used to move the raw materials, note any major dust clouds.
8. Make notes on the lengths and locations of unpaved roadways. Ask what frequency these roadways receive dust preventive treatment such as water, oil or calcium chloride. Observe the traffic on these roadways, and note whether or not a significant cloud is generated by vehicular movement. Observe the paved, macadamized and gravel roads for latent dust. Occasionally these roads may become burdened with dust and result in another source for fugitive dust.
9. Observe the transfer points along belt haulage ways. If no dust is noted, no further inspection is required here.

The Inspector's Worksheet which follows may be useful for record keeping. Interpretation of these observations is heavily dependent upon the pertinent regulations governing fugitive dust emissions. Since many of these plants are located on large plots of land, it is important to discriminate between in-plant housekeeping problems and emissions which cross the property line. If fugitive dust violations are apparent, take appropriate action.

3. COKING

This is a major source of particulate emissions. Other emissions include hydrocarbons, sulfur dioxide and odors. Emissions are mainly a function of facility design.

INSPECTORS WORKSHEET

FOR RECEIVING, STORING AND HANDLING OF RAW MATERIALS

Plant Id.____

Date of this Inspection____________ Date of last Inspection____________

Type of Plant____

Capacity of Plant____

Source Location	Type Material	Wind Direction Wind Speed (mph)	Plume Description	Preventive Measures
Sample Coal stacking conveyor	coal	SW/20	Moderate black dusting	Telescoping chute
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				

3.1 Process Description

Coke is a cellular form of carbon produced by thermal distillation of coal. As crushed coal is slowly heated in the absence of air to a temperature above 2,000°F over a period of 10-30 hours the moisture, volatile hydrocarbons, and about one-half of the sulfur are driven off. The metallurgical coke which is produced is used in blast furnaces as a source of carbon. Approximately 65 million tons of coke are produced annually in the United States.

An individual slot-type coke oven is a long, tall narrow chamber with doors at each end. Older ovens may be 10 feet high, 30 feet long and 14 inches wide. New ovens might be 18 feet high, 60 feet long and 20 inches wide. For material handling purposes coke ovens are constructed in batteries of as many as 100 ovens.

In its simplest form, the process consists of filling the oven with crushed coal. The oven is then sealed to prevent air infiltration and heat is applied to the exterior walls and the by-products piped to a recovery system. When the coking cycle is completed both end doors are removed and the coke is pushed out.

Actual coking practice is complicated because of the need for precise controls and sophisticated mechanical equipment, but the basic process is as described.

Coke oven batteries are designed so that refractory side walls of the oven taper slightly from end to end to prevent sticking of the charge during pushing. The walls between the ovens form refractory brick combustion chambers, designed to allow even heating of the ovens.

Since the oven operating temperatures are within a few hundred degrees of the working limit for the refractories the temperature control system has many safeguards. Protection of the refractories is an important maintenance factor in a coke plant as these refractories are susceptible to total failure if subjected to thermal shock. Once initially heated, many batteries are not cooled through their entire working life.

Thermal economy demands that some of the heat supplied to the combustion chambers be recovered before venting to the stack. Regenerators consist of large brick checker chambers.

Uniform heating over the entire oven wall area is a prime consideration in quality control of coke. Non-uniform heating is usually caused by air infiltration at the ends of the oven which leads to a plug of incompletely coked material at the ends of the charge. This causes a heavy black smoke cloud as the remaining volatiles burn. This is known as a "green push."

Coking proceeds from the walls toward the center. The ends take longer to coke than the middle because the end doors are unheated.

The preparation of coal requires considerable effort. Coal of different volatile contents usually must be blended to get a mixture with proper thermal coefficient of expansion. Coals must be crushed to 85 to 90 precent below 1/8-inch before blending.

Sulfur is an undesirable element in steelmaking. Metallurgical grade coal is nearly always below 1 percent sulfur content.

Blended coal is sent by conveyor belt to large silos atop the coke oven battery. The ovens are charged by a wide-gauge vehicle called a larry car, which traverses the entire battery. The larry car carries a precisely weighed single charge of coal to individual ovens.

Each oven has three to five charging ports on the top. The end doors are in place during charging. The charge of 10 to 30 tons of coal is dropped into the oven in less than a minute in most cases. Surface moisture and some light hydrocarbons are vaporized as the fine coal comes in contact with the hot refractories. A cloud of steam, brown smoke, and some dust is generated during charging.

The top of the coal charge is leveled by a long bar inserted from the pushing side of the battery. The leveling rod goes through a small "chuck door" located on the oven door. The leveling bar is part of the pushing machine.

After the charging is completed, the charge-port lids are replaced. This is accomplished manually or, at newer plants, by a machine on the larry car. The heavy round tapered lid seats against a steel sealing ring embedded in the oven brickwork. The machine-placed lids are spun in place and generally seat much better than hand-positioned lids. If the mating surfaces do not meet due to wear or warpage, tarry deposits or particles of coal eventually complete the seal. Coal dust left on the seat or swept around the lid will smoke as the lid gets hot. Sometimes a clay sealer material is applied around the port cover to reduce emissions.

Sealing of the end doors of the ovens is an important but difficult step in the coking process. Some older ovens have luted doors which are sealed by the application of a mud-like troweled material around the periphery of the door. Operating personnel apply this luting material by hand. Newer ovens have knife edge seals. These doors have a thin metal strip around the edge which butts against the door jamb of the furnace. They have some degree of manual adjustment, allowing them to fit worn or warped jambs. A positive seal is not actually made until a tar deposit builds along the hairline crack at the mating edges. Even clean doors in good condition will leak for some period of time until a seal is formed by the accumulation of tar from the leaking vapors. It is necessary that the doors and jambs be scraped clean of this tar deposit between each coking cycle to allow the doors to seat properly. This cleaning is accomplished by machines and/or by hand. Generally, machine cleaning must be supplemented by hand cleaning.

Each oven has one or two evacuation pipes at the top corner for the recovery of volatiles. Called stand pipes or ascension pipes, they carry the gases to a collecting main which runs the length of the battery. This is the start of the by-product recovery system shown by Figure 3.1.

The collecting main is held at a controlled slight negative pressure by an exhauster. Sprays of flushing liquor cool the gas and condense a mixture of tars and high boiling organic and inorganic chemicals. Flushing liquor is recirculated. Depending upon whether the system has one or two collecting mains, between 1,000 and 2,000 gallons of liquor are used per ton of coke.

A tar precipitator removes mist to prevent plugging of the remainder of the system. A weak-sulfuric acid scrubber removes ammonia and forms ammonium sulfate. Light and heavy organic chemicals are recovered in a series of steps similar to refinery processes. Some sulfur is usually recovered for making the sulfuric acid used in the ammonia scrubber.

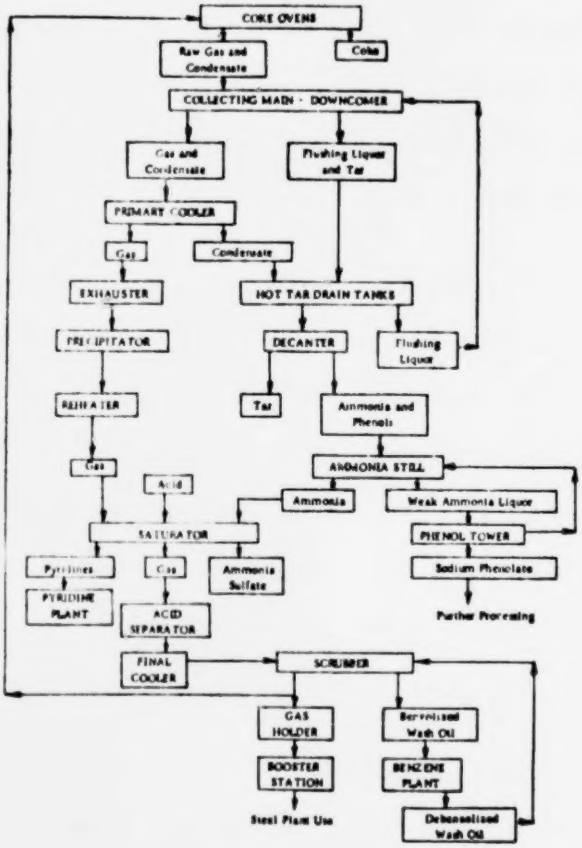

COKE OVENS
Raw Gas and Condensate
Coke
COLLECTING MAIN - DOWNCOMER
Gas and Condensate
Flushing Liquor and Tar
PRIMARY COOLER
Gas
Condensate
EXHAUSTER
HOT TAR DRAIN TANKS
PRECIPITATOR
DECANTER
Flushing Liquor
REHEATER
Tar
Ammonia and Phenols
Gas
AMMONIA STILL
Acid
Ammonia
Weak Ammonia Liquor
SATURATOR
PHENOL TOWER
Pyridines
Gas
Ammonia Sulfate
Sodium Phenolate
PYRIDINE PLANT
ACID SEPARATOR
Further Processing
FINAL COOLER
SCRUBBER
GAS HOLDER
Benzolised Wash Oil
BOOSTER STATION
BENZENE PLANT
Steel Plant Use
Debenzolised Wash Oil

FIGURE 3.1 BY-PRODUCT PLANT FLOW SHEET

The resulting coke oven gas has a heating value of about 550 Btu/cf and is an important fuel in a steel plant. Coke oven gas supplies about 70 percent of the fuel for heating the ovens; the balance is supplied by blast furnace gas and small amounts of natural gas or oil.

Raw coke oven gas contains from 3.5 to 4.5 grains of hydrogen sulfide per standard cubic foot. This is a fuel sulfur content equivalent to coal containing 1.2 to 1.6 percent sulfur. Some plants have desulfurization processes which reduce the hydrogen sulfide content to below 0.5 grains per standard cubic foot.

The coke plant operator has some degree of control over his production rate because coking is a time and temperature related process. Lower temperatures mean longer coking times. If, for example, a 60-oven battery was on a 15 hour coking cycle this would mean that an oven would be charged every 15 minutes. Extending coking time to 20 hours would mean a charge every 20 minutes. Most plants schedule their charging and pushing times so that lunch breaks and shift changes are periods of light activity.

At the completion of the charge both end doors are removed and the incandescent coke is pushed out of the oven by a large ram on the pushing machine into a quench car. This is a slope-bottom car which is self-propelled on a track. When the hot coke drops into the quench car a strong thermal updraft is created, lofting dust into the air.

The quench car travels to the battery quench tower, a large brick or wooden chimney. A large amount of water - typically about 4,000 gallons - deluges the hot coke in a period of about two minutes. Roughly one-half of the water is vaporized forming a heavy steam plume. Some of the water droplets from this plume fall in the immediate vicinity of the quench tower.

The quench car dumps the coke on a coke wharf, a sloping surge area which feeds a belt conveyor. The finished coke goes through a rough crushing stage to break up large lumps and is screened. Coke fines, called breeze, are undesirable in blast furnaces because they impair the porosity of the burden. Coke breeze is used in the sinter plant as a source of carbon.

3.2 Process Control Operation

Coal is sent from the stockpiles to the crushing and blending station. This operation will have a dust collection system for control of particulate emissions. Some plants add oil to the coal at this point as a final adjustment to the density of the blended coal, but it is becoming less common. Oil reduces dusting during handling.

Long runs of belt conveyors carry the coal to the silos above the ovens; the weigh bins below the silos drop the coal into the larry car. The dust created at this point might be considered fugitive dust or a housekeeping burden.

The charging of the ovens is a major point-source of visible emissions. Several new emission control systems are being investigated. Barring changes in the mechanical design of the system, control practice consists primarily of reducing the total time of the charging. This means getting the lids back on as soon as possible. Stand pipes must be closed off during pushing and before charging to prevent air entering the main. The oven should be "on the main" before charging is completed. This significantly reduces the emissions from the charging ports and chuck door while they are open. The sealing of the lids should be complete within one-half hour after charging. Some plants pour a mud slurry sealer around the lids to provide a seal.

Coal dust should be swept away from the lid before it gets hot and beings to smoke. The top of a coke oven is a hot, dirty place to work.

During the coking cycle, there are two sources of leakage from the end doors, whether they are the self-sealing or luted type. The first is leakage due to doors that are not properly cleaned and adjusted, or because of excessive warpage of seal strips or jambs. Improper application of the luting compound has the same result. The emissions are a heavy brown smoke during the first stages of coking and continue as yellowish smoke for many hours. The second type of leak is inherent as the positive seal forms through the accumulation of tars along the mating edges of the doors and jambs. This light brown or yellowish smoke will stop after about an hour of coking. Long time emissions are undesirable and preventable. Light emissions for less than one hour are the best which can be attained at this time. The amount of emissions from end door leakage is heavily dependent on the operating personnel.

Green coke is the greatest source of emissions during the pushing operation. The amount of smoke is directly related to the amount of insufficiently coked coal. Green coke performs poorly in the blast furnace; thus it is rarely made deliberately, although in some cases pressure to make up lost time or provide material ahead of schedule can lead to a decision to push ahead of the normal cycle time. A small reduction in the coking time can result in a large increase in the amount of emissions.

Operators are sometimes surprised by a green push which is caused by defective burners or flues. This is most apt to happen in old deteriorating batteries. Overfilling an oven is another cause of a green push.

In the by-product recovery section of the plant, odors will be present where flushing liquor sumps and tar decanters are sources of both ammonia and organic odors.

In newer plants the handling systems for foul water and recovered chemicals are designed to reduce odorous point sources. Older plants face problems with pump and valve seals, leaky gaskets, and occasional spills. Maintenance is the most important factor short of total redesign in controlling organic emissions in by-product plants.

The steam plume rising from the quenching tower carries dust ranging from 1/16-inch down to micron sizes into the atmosphere. This is unavoidable with the towers currently being used. In a few plants, baffles in the tower contain some of the grit emissions. In some cases, contaminated water is disposed of in the quenching process, but this undesirable practice can result in emissions of ammonia, phenol and other air pollutants.

At the coke screening station, transfer points and screens have dust collection systems. Dusting during coke handling is generally not a problem.

3.3 Enforcement Procedure

A visual inspection should be made of the entire plant facilities. Trace the material flow from receiving the crushed coal in the storage bin above each battery of ovens to the delivery of coke to the blast furnace. Also trace the by-product process from the coke ovens to finished product.

Record the weight of the batch charge, the length of time for the coking cycle, and the temperature range maintained in the oven. These items are controlled and monitored by the plant. The frequency, degree and cause of green pushes are probably not recorded but possibly can be established by talking to operating personnel. Observe if good housekeeping practices are maintained around the charging ports and that lids are properly seated and sealed to eliminate unnecessary smoking during coking.

Inquire if there is an established maintenance program to keep oven doors in proper adjustment and learn how the doors and jambs are cleaned of tar deposits and observe the battery during the coking cycle to determine the effectiveness of the door seals. Compare the amount of leakage at the beginning of the cycle to the leakage a few hours later.

Determine if waste water and/or weak liquors are being fed to the quench tower sump for disposal by evaporation. Follow the by-product recovery system, noting any odor or fume emissions. Take note of vents from scrubbers and exhaust fans and inquire if the sulfur content of the coke-oven gas is checked and recorded. In some plants hydrogen sulfide is stripped from the gas and either converted to sulfuric acid or vented. Newer processes produce pure sulfur from the stripped H_2S. Determine the process being employed, if any, by the particular plant and what form of emissions are being released to the atmosphere.

Visible emissions are the simplest means for estimating particulate and control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plumes and if in excess of allowable limits, take appropriate action.

With the sulfur content and volume of coke oven gas used as fuel, the approximate SO_2 emissions can be calculated. Take note of the ultimate disposition of any sulfur stripped by recovery plants. Gaseous products, if burned, should be included in the emissions calculation. Compare with allowable emission levels and take appropriate action.

Short of changes in plant design, maintenance and housekeeping are the two factors which affect emissions from coke ovens. After a few visits to a plant over a period of months it will be possible to make a qualitative judgment concerning deteriorating or improved performance.

4. SINTERING

This is a major particulate and minor gaseous emission source. Emissions are mainly a function of control system design and operations.

4.1 Process Description

Sintering is the principal in-plant recycling process. Ore dust, blast furnace flue dust, turnings and borings, and various otherwise unusable materials are converted into a high quality blast furnace feed material in the sinter plant. There are about 50 sinter plants in the United States.

In the early 1900's, unsized raw ore was used as the principal iron-bearing raw material in blast furnaces. Researchers found that higher production rates were possible if the raw materials were stipped of fines. Sinter plants were developed to recover the iron in flue dust and ore fines.

As the supply of high quality domestic ore dwindled, pelletizing was developed as a beneficiation method for the available lower grade ores.

The size of pellets was held within close limits and blast furnace operators found that even better production rates were possible.

Current blast furnace research indicates that sized-sinter (as opposed to unsized) is a very good raw material. Sintering is a flexible process and some blast furnace raw materials can be added to the sinter mix with cost savings. These factors, in combination with the recycling aspects of the sintering process, indicate that sinter plants will be a permanent part of an integrated steel plant.

The sintering process,depicted in Figure 4.1, requires blending of the iron-bearing materials with flux and solid fuel as a first step. This mixture is deposited on a bed up to 18 inches deep and 13 feet wide. This bed is supported on an endless belt of grate-type pallets which move slowly to carry the raw material through the process.

The bed of raw materials is leveled before it passes under a combustion zone. Suction under the grate creates a downflow of air. Combustion in the bed is initiated by a gas-fired heater a few inches above the top of the sinter. Coke oven gas is the most common combustion fuel.

At this point, the top surface of the bed has been ignited. As the sinter moves slowly down the sinter line, air is downdrafted through the bed to maintain combustion, producing a fused, porous material. At the discharge end of the sinter line the bed is discharged from the grates by gravity. The large chunks are broken by a tooth and comb breaker and fines are removed by a hot screen for recycling to the feed.

The hot sinter goes to an air cooler, from which it is belt-conveyed to screens. Finished sinter is transported from storage bins to the blast

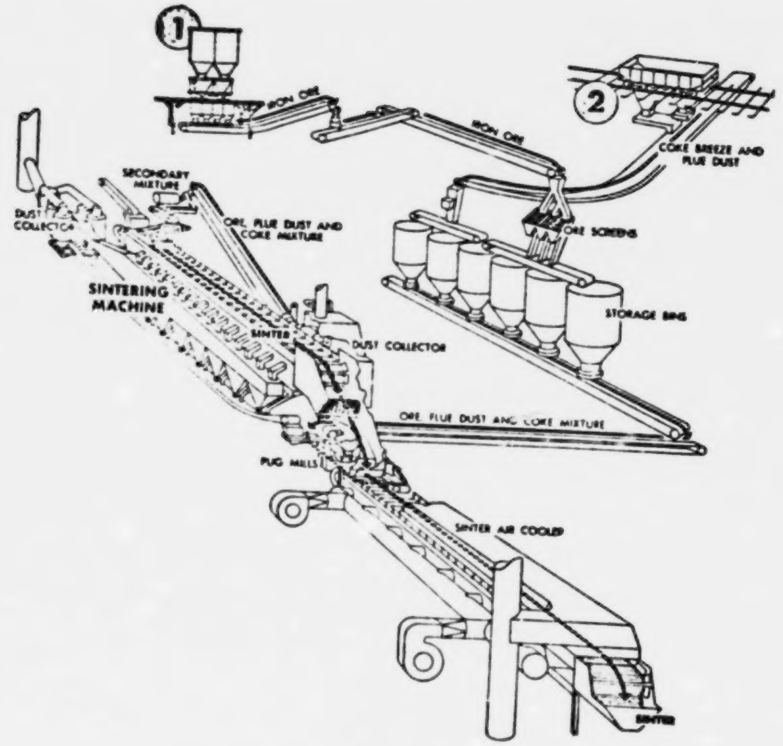

①
IRON ORE
IRON ORE
②
COKE BREEZE AND FLUE DUST
SECONDARY MIXTURE
DUST COLLECTOR
ORE, FLUE DUST AND COKE MIXTURE
ORE SCREENS
SINTERING MACHINE
STORAGE BINS
SINTER
DUST COLLECTOR
ORE, FLUE DUST AND COKE MIXTURE
PUG MILLS
SINTER AIR COOLER
SINTER

FIGURE 4.1 SINTERING PROCESS

furnace by railroad car. The sinter mix must contain a carefully blended amount of carbonaceous material to give the correct combustion temperature and burning rate. Coke breeze is the preferred material, with anthracite coal an alternative.

A flux, such as limestone, must be included in the mix for fusion of the burned sinter. An important new aspect of sintering is the inclusion of excess limestone in the sinter mix. Limestone added in the sinter reduces this addition at the blast furnace. Normal limestone rates for standard sinter plant operation is on the order of 200 lb/ton while "high lime" or "superfluxed" sinter takes up to 700 lb/ton.

The feed must be thoroughly blended and of uniform bulk density on the grate to prevent uneven air distribution. If hot spots develop, or if the bed develops holes, the operation is disrupted and poor quality sinter results.

Suction under the bed is developed by a high pressure induced draft fan. Under the sinter bed are a series of "wind boxes" which exhaust into a plenum. The wind box stack gases are the principal air pollution emission source at the sinter plant. They contain particulates and a variety of gases. About two-thirds of the sulfur in the feed materials is trapped in the sinter by the flux. If mill scale, turnings, or other oily feed materials are used there can be oil in the stack gases. Nitrogen oxide concentrations are generally not significant because of the relatively low combustion temperature. Typical stack temperatures are about 300°F.

Cyclones are used upstream of the fan to provide protection from the highly abrasive sinter dust. The dust caught by this cyclone becomes part of the sinter plant feed.

At the discharge end of the sinter machine there is a significant thermal head. Dust is created as the sinter falls to and through the breaker, passes over the hot screen and drops to the pan conveyor. From this point in the process the only air pollutant is particulate matter.

Sinter coolers come in various sizes and shapes. Some are updraft, some downdraft, and a few are shaft-type designs. Depending on the design and the degree of hot screening, the cooler can be a substantial to minimal point source of particulate emissions.

Once cooled, sinter is crushed and screened to appropriate size. The conveyor transfer points and the screens are all potential sources of particulate emissions.

4.2 Process Control Operation

Careful records are kept of raw material mixes and the production rate, but instrumentation at sinter plants is generally unsophisticated. Wind box suction is a useful indicator of the stability of the process but it may not be recorded.

The maintenance rate is high at sinter plants and they are typically shut down one shift per week to perform necessary work.

Air pollution control systems for wind box gases, in addition to the cyclones mentioned above, are usually precipitators. Scrubbers or baghouses may also be used. With the process change to high lime sinter many plants with precipitators found that efficiency was drastically reduced. The lime dust altered the resistivity of the particulate matter.

Scrubbers have problems of high corrosion and erosion as well as scaling in water lines and a water pollution problem.

Sinter plant wind box air pollution control is a difficult problem because of process flexibility. Changes in feed material or process operation can have a drastic effect on the air pollution control equipment efficiency.

Control equipment throughout the rest of the process is much more straightforward. The design of hoods and ductwork must be adequate to capture the particulates at the source operations. Once captured, collection of the particulate is not difficult.

At the discharge end of sinter machines the air is hot and the dust particles may still be glowing red; therefore, glass fabric baghouses and medium energy wet scrubbers must be used to collect this dust. Baghouse problems center around broken bags and scrubber problems,including plugging of water lines and the erosion of scrubber internals.

The dust from sinter handling and screening is usually collected by baghouses. The dry dust can be directly recycled to the feed of the sinter line.

4.3 Enforcement Procedure

Emissions from sinter plants consist principally of particulate matter, with some sulfur dioxide. Particulate control abatement equipment is used on all plants.

The objective of sinter plant inspections is to establish compliance with the particulate and sulfur dioxide emission regulations. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design levels.

Both plant and emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to plant inspection. Production levels are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

Familiarization with the process is a necessary preliminary step. Walk through the entire process from the mix house to the loadout bins and become familiar with the process control instrumentation.

Trace all ducts which are part of the air pollution control system. Make a record of the type of control equipment used and take special note of its instrumentation.

Make a detailed flow chart or obtain one from the plant to better understand the process.

Inquire about maintenance and operational problems with the pollution control systems. A site visit during a maintenance shutdown would be useful in clarifying any situations which are confusing when the plant is in operation.

A precipitator on the wind box gases will have an efficiency which is sensitive to gas volume, temperature, and particulate composition.

Establish whether control devices are operated above, at, or below design capacity.

Since changes in the feed material may drastically affect wind box emissions, discuss this point with operating personnel. If the sinter mix is different from that for which a precipitator was designed, precipitor efficiency may be adversely affected.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plumes and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine point(s) of origin and require corrective action.

5. BLAST FURNACE

The furnace is a minor emission source. The ancillary operations are minor sources of particulate and sulfur dioxide emissions.

5.1 Process Operation

The blast furnace is the primary production unit in the iron and steel industry for the conversion of iron-bearing raw materials to high carbon pig iron, commonly known as hot metal. This pig iron contains roughly 4 percent carbon, 0.05 percent sulfur, 1.5 percent silicon, 0.4 percent phosphorous and 1.5 percent manganese. It is used almost exclusively as a raw material in steelmaking furnaces where further purification and alloying produces steel of the desired composition. The steelmaking process reduces the concentration of the elements noted above, which are considered impurities in most steel specifications. A small quantity of the hot metal produced is cast directly as pig iron. There are a few blast furnaces in the United States which produce ferroalloys.

Ironmaking technology has advanced rapidly in the last fifteen years, with great attention to the economy of scale attained by larger blast furnaces. Blast furnaces are generally over 100 feet tall and may be 30 feet or more in hearth diameter. The blast furnace, Figure 5.1, is roughly pear-shaped, with the hot metal and slag formed at the hearth. The blast furnace uses more air than any other raw material, by weight. Thermal economy demands that this air be preheated before it is injected into the hearth through a series of nozzles calle "tuyeres."

The metallurgy of the blast furnace involves reducing iron oxides to elemental iron. Carbon, added in the form of coke, acts as the reducing agent. Limestone is added as a flux so that a slag can be formed for the separation and retention of sulfur, phosphorous and silicon. Air is provided to burn the coke to attain the necessary reduction temperatures. The gases produced during this smelting process consist of about 25 to 30 percent carbon monoxide, water vapor, nitrogen, carbon dioxide and hydrogen. The gases also contain particulate matter. The gas is used as fuel following the removal of particulate matter.

Approximately 30 percent of the cleaned blast furnace gases are utilized to preheat the air supplied through the tuyeres, the balance of the gas is used throughout the steel plant. It has a low heating value of about 75 to 100 Btu/cf. The burners used for blast furnace gas are specially designed to maintain combustion. Many of the applications where blast furnace gas is burned involve heating of chambers containing refractory bricks; trace amounts of iron-bearing particulate matter can cause

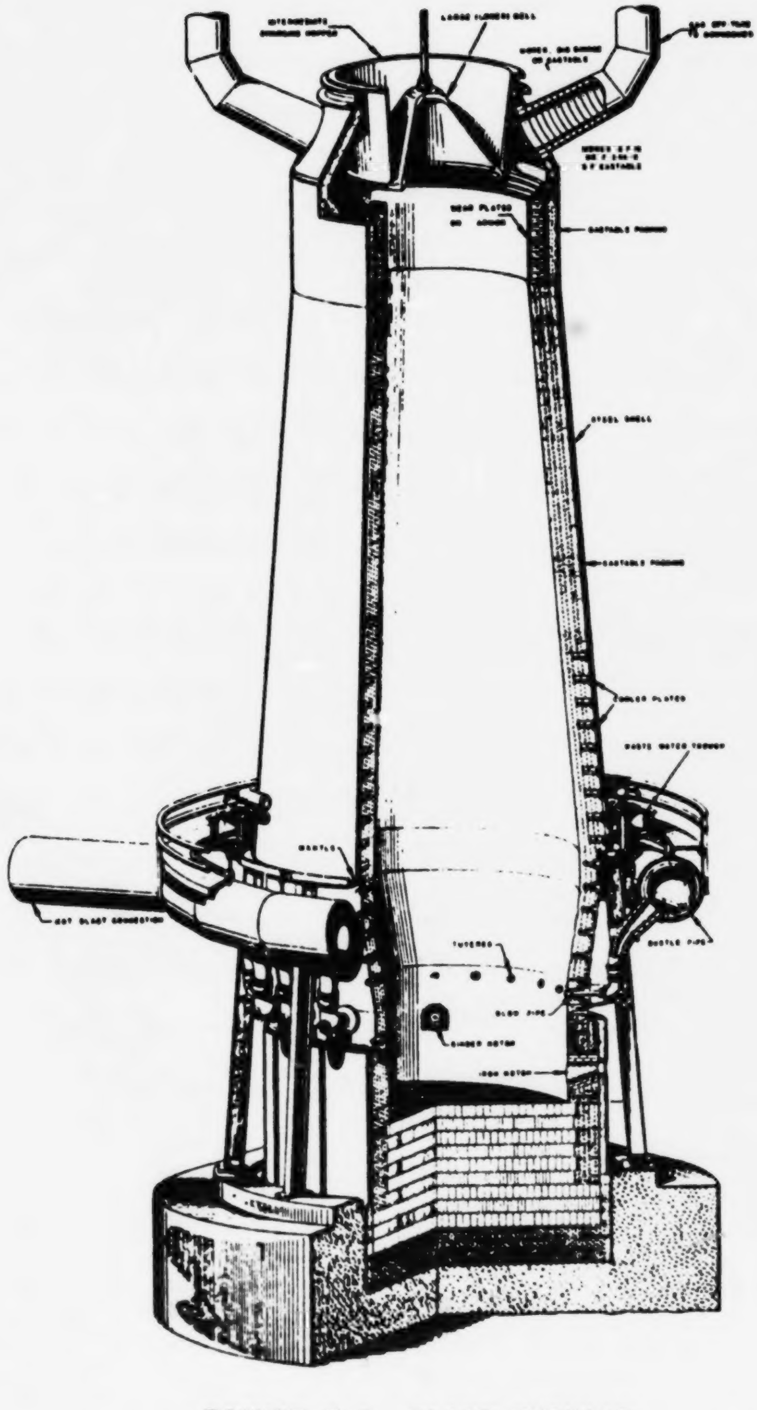

INTERMEDIATE CHARGING HOPPER
GAS OFF TAKE TO DOWNCOMER
WEAR PLATES OR ARMOR
STEEL SHELL
COOLER PLATES
MANTLE
HOT BLAST CONNECTION
TUYERES
BUSTLE PIPE
BLOW PIPE
CINDER NOTCH
IRON NOTCH

FIGURE 5.1 BLAST FURNACE

slagging of these refractories. The slagging problem and the difficulties in burner maintenance with dirty gas have led to common industry practice of cleaning the blast furnace gases to a particulate content of less than 0.01 gr/cf in almost all cases, and to as low as 0.001 gr/cf in some new installations.

Raw materials are introduced to the blast furnace through a system of two or three pressure sealing bells at the top of the furnace. Research has shown that blast furnace production can be increased by operating the furnace under high positive pressures of approximately 100 in. H_2O as measured at the top of the furnace. This high top pressure must be dissipated before the cleaned blast furnace gas is distributed to plant fuel use; however, high energy venturi scrubbers can accomplish the particulate removal concurrently with reduction of gas pressure. In some plants a combination of wet scrubbers and wet electrostatic precipitators are used. High efficiency gas cleaning devices are preceded by an inertial or cyclone dust collector (dust catcher) to collect some of the particulate matter in the dry state. This is recycled to the sinter plant.

As raw materials are introduced at the top of the blast furnace they fall to the top of the burden of raw materials already in the furnace. The hottest temperature zone in the blast furnace is at the hearth level, where the burden is molten. One operating problem with blast furnaces is maintaining an even downward flow of the burden toward the hearth. At times the burden does not slide downward uniformly because of an arch of partially melted raw material. If this arch breaks precipitously or "slips", the furnace top pressure increases abruptly. This results in heavy particulate discharges from the top of a blast furnace as a safety valve opens to prevent rupturing of furnace components. Improved control of furnace operation and improved raw materials have reduced the frequency of these slips to the point where they are now an unusual occurrence.

The raw materials are delivered to the bell system at the furnace top by conveyor belts or skip cars. Particulate emissions from material handling depend upon the design of the system at any particular plant.

Hot metal and slag are drawn from the furnace at regular intervals through separate tap holes at the hearth levels and are directed through refractory runners to slag pots or hot metal transfer cars. A large shower of sparks (Figure 5.2), generally accompanies the opening of a tap hole. Emissions of sulfur dioxide and particulate matter are inevitable as the material passes through the open runners in transit to the receiving vessels.

Particulate emissions during hot metal tapping consist of iron oxide fumes, manganese fumes, and "kish". Kish is a platelet-shaped graphite material released as the temperature of the carbon-saturated hot metal is reduced. Kish particles tend to be oily and cause a general housekeeping problem in the tapping area.

Sulfur emissions released from the slag as its temperature is reduced are mainly in the form of sulfur dioxide, although some hydrogen sulfide is formed.

Nearly all of the hot metal produced is used in steelmaking furnaces; however, minor amounts are consumed by foundries within the steel plant for the manufacture of heavy castings such as ingot molds. At some plants hot metal is cast into pigs as a finished product.

5.2 Process Control Operations

Accurate records of furnace top pressure and temperature are kept at all blast furnaces.

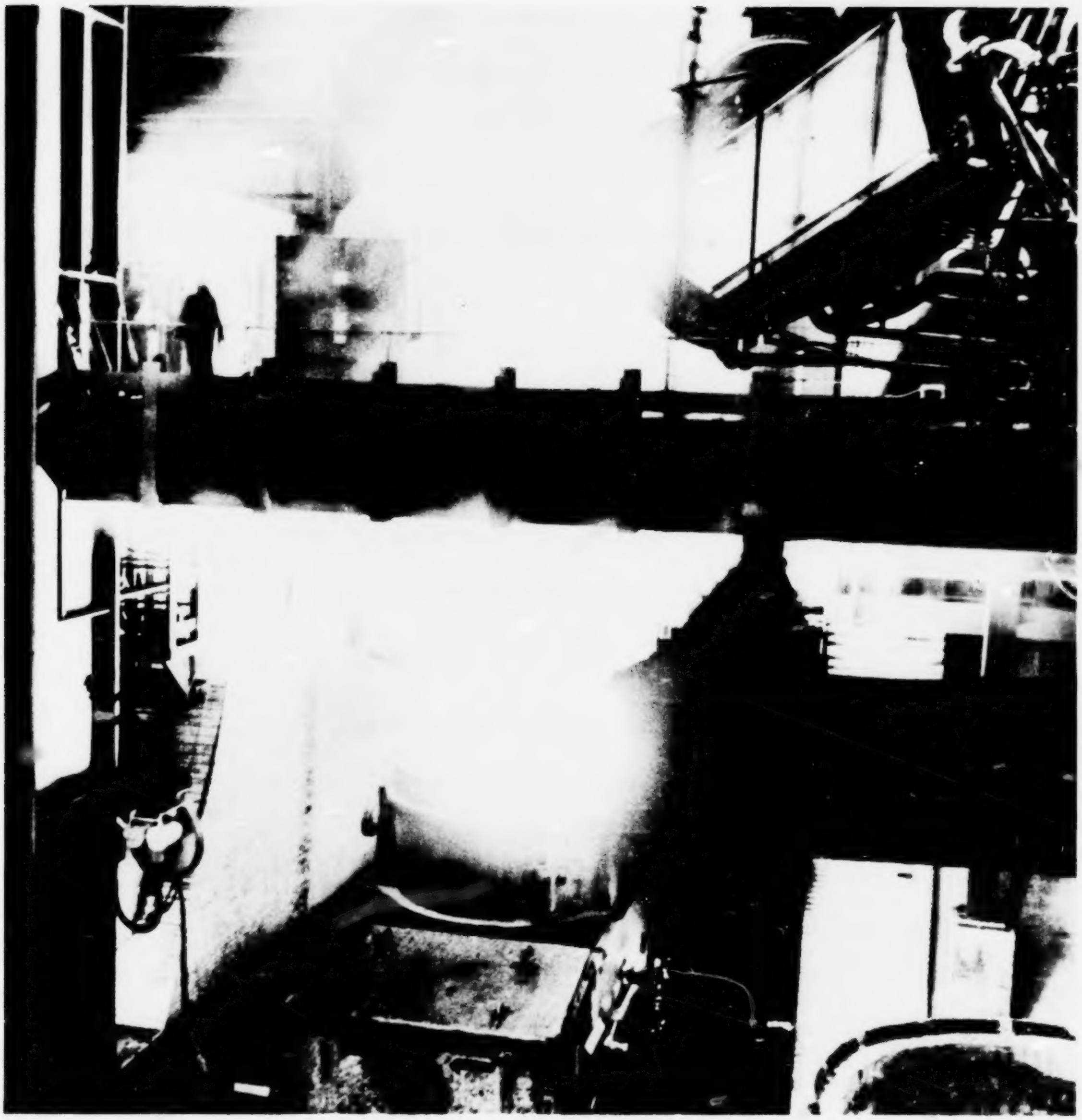


FIGURE 5.2 TAPPING

In some plants frequent tests are conducted for the particulate content of the cleaned blast furnace gas, and if so, these data should be available. In other plants records may be kept of the venturi pressure drop and water flow rates. These serve as an adequate substitute for frequent measurements of particulate content to monitor the cleanliness of the fuel gas. The dust content of the cleaned gas is not a major factor in the evaluation of air pollutant emissions from blast furnaces since process operating upsets (burner fouling and refractory slagging) are so serious that the condition would not be allowed to exist in an uncorrected state.

Tapping fumes may escape the cast house as visible emissions (Chapter 7). The dumping of dust catcher hoppers is another point of potential particulate emissions.

Raw material composition and feed rate records, as well as records of hot metal and slag production, are maintained. Frequency and duration of slag and hot metal taps are also recorded.

5.3 Enforcement Procedure

The blast furnace is a minor contributor to air pollution so that only a cursory inspection is needed. The major items to be evaluated are the adequacy and condition of the dust control systems at the raw materials handling area, frequency of slips which cause emissions, and dust catcher dumping.

A large quantity of process data on raw materials, operating pressures, temperatures, and production rate are available. These will be of little value unless there is an effect on emissions.

A change in raw material composition or rate can, in some cases, cause slips. The furnace-top pressure charts can be reviewed for "spikes" to verify the occurrence of slips.

Visible emissions are the simplest means for estimating particulate emissions. The enforcement official should estimate the percent opacity of these emissions, and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust, and if noted, determine point(s) of origin and require corrective action.

Inspect the dust catcher during dumping of the dust. Some plants have found it necessary to treat the dust before loading it into transfer cars (going to the sinter plant) because of heavy dusting.

Slag disposal (Chapter 12) is closely allied with blast furnace operation. These inspections can logically be made concurrently.

6. PIGGING OF IRON

This is a minor potential particulate emission source.

6.1 Process Operation

The high-carbon pig iron produced by the blast furnace can be cast directly into "pigs" ranging from 30 to 100 pounds each. These pigs are used for small castings in iron foundries and provide carbon additions in electric furnace or open hearth steelmaking furnaces.

Hot metal is poured from a transfer car into a small basin located above one or two endless belts of pig molds, (Figure 6.1). The line of molds travels slowly to the head pulley, where the solidified pigs drop out. Water-sprays cool the pigs. On the return (under) side of the endless belt the molds are sprayed with a lime water wash, used as a mold

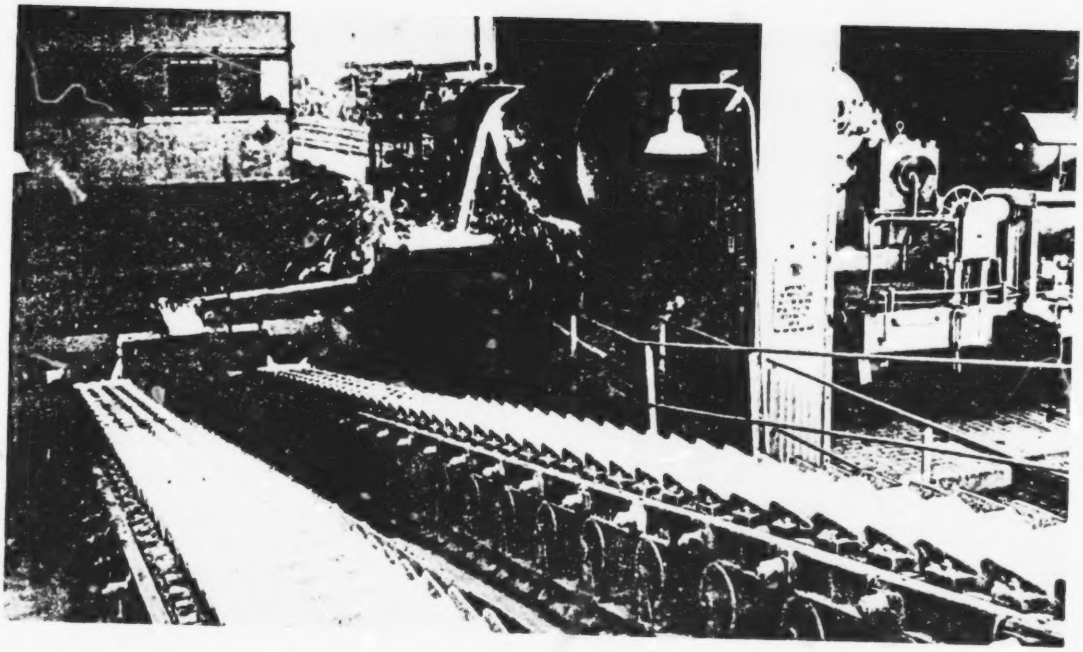


FIGURE 6.1 PIG CASTING MACHINE

release. Iron pigs represent only a small percentage of blast furnace production. Where pig casting machines are installed, they are seldom used for more than a few hours a week to meet product demand.

6.2 Process Control Operation

The pouring of hot metal generates minor amounts of iron oxide fumes and the rapid cooling of the hot metal creates kish, causing a local housekeeping problem. The water-sprays result in a heavy steam cloud at pig casting machines.

The only potential emissions are particulate matter, and this is slight because of the nature of the process and the low percent utilization of pig machines. Air pollution control equipment is not used.

6.3 Enforcement Procedure

Observe the area of the pig casting machine to note the presence of visible emissions of particulate matter. If required, take appropriate action.

7. IRON CASTING

This is a minor source of particulate emissions.

7.1 Process Description

Periodically, the pig iron is tapped from the blast furnace and passed through runners to submarine-type open-top ladles. When the molten iron is released from the blast furnace, kish is emitted due to the rapid cooling of the carbon-saturated hot metal. The kish consists of graphite flakes, and due to its shape and low density can be carried long distances by a light breeze. Its oily tenacity makes it difficult to remove after it has settled. Other substances which are emitted during the tapping operation include manganese oxide and sulfur dioxide. The particle size of the metallic fumes is in the sub-micron range.

Slag is tapped from the blast furnace and passed through runners to slag pits or ladles. Emissions from the slag tapping operation include sulfur dioxide, hydrogen sulfide, and fine particulate matter consisting of metallic oxides.

7.2 Process Control Operation

Very few blast furnace cast houses will have air pollution control systems.

7.3 Enforcement Procedure

The enforcement official should make an overall inspection of the blast furnace from the exterior of the building during the casting operation as air pollution control devices are not commonly used for casting operations.

The process weight can be determined from the production data.

If pollution control ventilation hoods exist at the tapping location, over the runners and/or at the ladle filling station, inspection should be made during tapping. Such systems should control the fumes. The control equipment should be evaluated and operating data obtained. Personnel and plant safety considerations must also be observed at all times.

Visible emissions are the only means for estimating particulate emissions. The enforcement official should estimate the percent opacity of the emissions and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust and if noted, determine point(s) of origin and require corrective action.

8. OPEN HEARTH FURNACE

This is a major potential particulate emission source. Emissions are mainly a function of control system design and operation.

8.1 Process Description

Steelmaking is the conversion of pig iron, scrap steel, and other ingredients into specification steel. The "open hearth" furnace (Figure 8.1) consists of a large hearth, fully enclosed, that is used to bring the interior temperature to 3000°F. The furnace is lined with refractory. An open hearth is heated with oil, natural gas, tar, or coke oven gas. The type of refractory material has little effect on the quantity of emissions from these installations. Typical capacities of open hearth furnaces range from 100 to 400 tons per heat. The time required to produce a heat is usually about eight hours. High purity oxygen can be blown into the bath to accelerate production.

The basic raw materials in open hearth steelmaking are hot pig iron from the blast furnace and steel scrap. Figure 8.2 indicates the materials used in the production of one ton of steel in an open hearth furnace using oxygen. Process variables such as the amount of scrap, hot metal, fluxes, fuel, etc. are usually recorded on the operators daily log. These logs are generally kept in the control booth. Combustion air is preheated by a checker system (Figure 8.1) located adjacent to the furnace.

Pollutant emissions include particulates, sulfur dioxide and possibly fluorides. Most plants have a waste heat boiler to produce process steam.

The exhaust gases from the furnace pass through the checker system and waste heat boiler to the air pollution control devide. Figure 8.3 shows an open hearth furnace with an electrostatic precipitator.

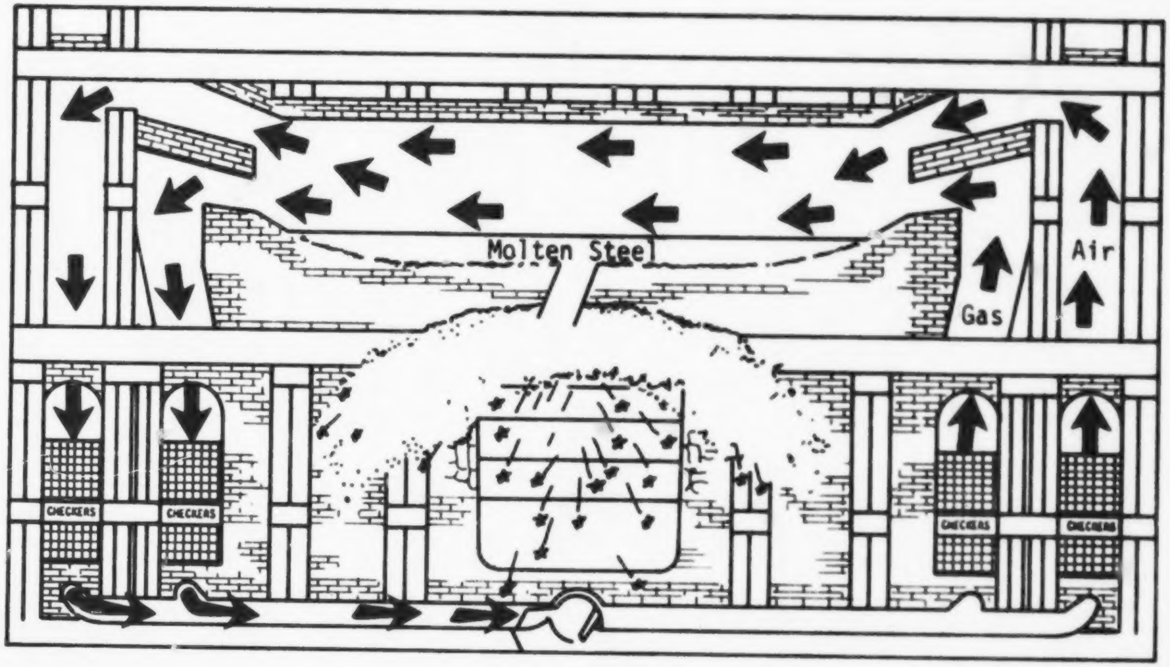
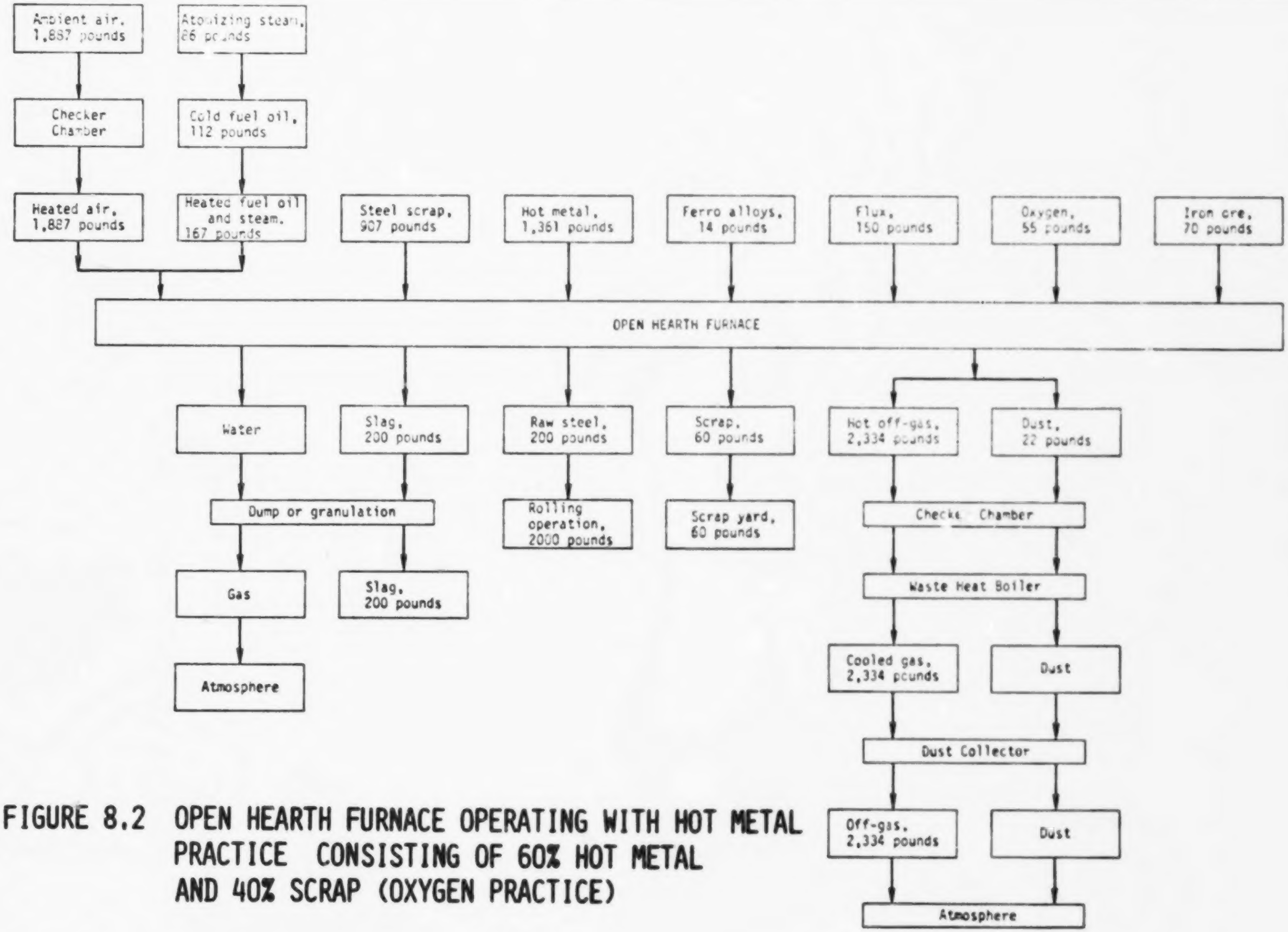

Molten Steel
Gas
Air
CHECKERS
CHECKERS
CHECKERS
CHECKERS

FIGURE 8.1 CROSS SECTION OF AN OPEN HEARTH FURNACE, SHOWING REGENERATIVE CHECKER CHAMBERS PREHEATING INCOMING AIR



Ambient air, 1,887 pounds
Atomizing steam, 86 pounds
Checker Chamber
Cold fuel oil, 112 pounds
Heated air, 1,887 pounds
Heated fuel oil and steam, 167 pounds
Steel scrap, 907 pounds
Hot metal, 1,361 pounds
Ferro alloys, 14 pounds
Flux, 150 pounds
Oxygen, 55 pounds
Iron ore, 70 pounds
OPEN HEARTH FURNACE
Water
Slag, 200 pounds
Raw steel, 200 pounds
Scrap, 60 pounds
Hot off-gas, 2,334 pounds
Dust, 22 pounds
Dump or granulation
Rolling operation, 2000 pounds
Scrap yard, 60 pounds
Checker Chamber
Gas
Slag, 200 pounds
Waste Heat Boiler
Atmosphere
Cooled gas, 2,334 pounds
Dust
Dust Collector
Off-gas, 2,334 pounds
Dust
Atmosphere

FIGURE 8.2 OPEN HEARTH FURNACE OPERATING WITH HOT METAL PRACTICE CONSISTING OF 60% HOT METAL AND 40% SCRAP (OXYGEN PRACTICE)

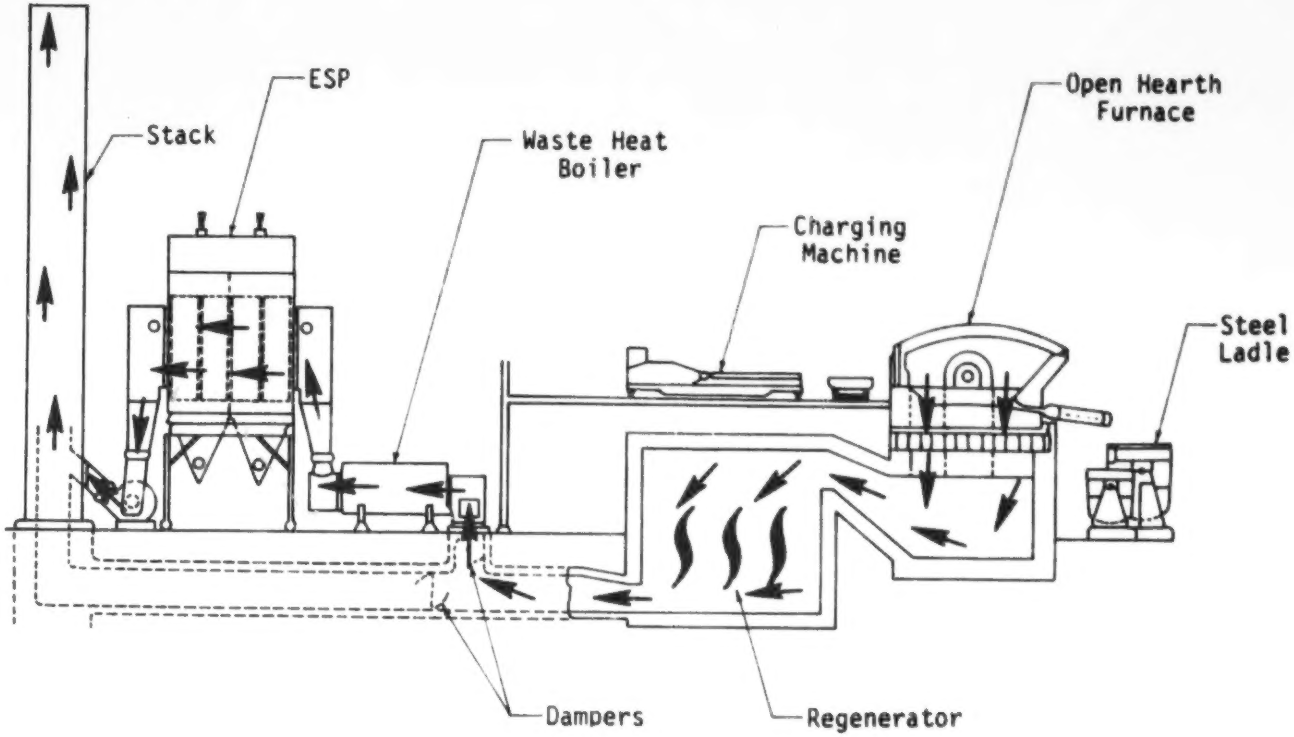

Stack
ESP
Waste Heat Boiler
Charging Machine
Open Hearth Furnace
Steel Ladle
Dampers
Regenerator

FIGURE 8.3 FLOW DIAGRAM FOR CLEANING OPEN HEARTH FURNACE GAS WITH AN ELECTROSTATIC PRECIPITATOR

8.2 Process Control Operation

The most important process control variables which affect air contaminant emissions rates are:

1. Type of fuel used,
2. Oxygen blowing rate,
3. Quality of raw material charged.

Emission level variations from different types of fuel are insignificant when compared to the increased emissions resulting from oxygen lancing. With oxygen lancing, variations in blowing rate (over the normal ranges found in practice) do not markedly affect particulate emissions.

Since even an open hearth furnace which does not use oxygen cannot meet current particulate emission standards, air pollution evaluations center on the abatement equipment.

As production rates at individual furnaces are increased, the system air volume must also be increased. This can cause an overload of the control equipment unless it was designed with over-capacity.

Production records detailing total production rate, charge composition, and other information will be available.

Air pollution control systems will normally serve several furnaces located in a single open hearth shop. Precipitators (Figure 8.3) and high-energy wet scrubbers are in use at open hearth shops. A stack opacity meter may be installed.

As hot metal is received in the open hearth shop it is transferred to a large holding vessel known as the mixer. From the mixer, hot metal is poured into individual ladles for transfer to the furnace. Some emissions of kish and iron oxide fume will be generated.

When the furnace is tapped, the hot metal and slag are poured into separate ladles, generating fumes.

The molten steel is generally poured or "teemed" directly into ingot molds in the open hearth shop. Emissions from teeming are minimal, but when lead is added to the molds, a separate ventilation system and baghouse are usually operated.

8.3 Enforcement Procedure

The objective of open hearth shop operation inspections is to establish compliance with particulate emission regulations. In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to plant inspection. Production levels and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

The shop may have a control booth near the units for monitoring purposes so the enforcement official should have little difficulty assessing the current operating status of the furnaces by observing the many recorders, gauges and logs which are normally kept.

For those open hearth shops which use electrostatic precipitators to reduce atmospheric emissions, the problem of enforcement becomes one of maintenance on the electrostatic precipitators. Most of the time the problem with precipitators will be dead sections (Part VII discusses the

INSPECTORS WORKSHEET

FOR STEEL PLANTS

GENERAL

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

Type Furnace: Open Hearth, BOF, Electrical Arc__________________

OPERATING VARIABLES

Steel Production Rate__________ tons/heat

No. of Heats per day__________

No. of Furnaces Operating__________

This Heat: pounds of scrap metal__________, pounds of hot metal________

Oxygen Blow_______________ scf/heat

Total Oxygen Clock Time__________min.

Spar Addition Rate________________lbs/heat

ABATEMENT EQUIPMENT

Unit / Parameter	1	2	3	4	Average in Industry
Particulate Efficiency (%)					95+%
Scrubber Pressure Drop (in. H_2O)					60+
Scrubber Water Flow Rate $\left(\frac{\text{gpm}}{1000\ \text{scfm}}\right)$					5 to 10
Precipitation Spark Rate, spm					50 to 400
Primary Voltage					20 to 100 kv
Primary Amps					1
Flow Rate,(scfm)					30,000 to 300,000
Inlet temp, (^{o}F)					300^{o}
Opacity or Ringleman No.					0

ACTUAL EMISSION DATA

Particulates__________lb/ton of Steel Produced

Sulfur Dioxide__________lb/ton

CO____________________lb/ton

Fluorides______________lb/ton

Tested by:__________________

Date:______________________

GENERAL OBSERVATIONS

Plume Capture____

Scrap and Hot Metal Addition________________________________

Pouring____

Duct Work____

Age of Control Equipment__________years

Time In______________

Time Out________________

impact of dead sections on reducing emissions). Most steel plants will keep records on the operation of a precipitator. Figure 8.4 indicates the type of report that has been prepared at one steel manufacturing plant for the electrostatic precipitators. If similar records are not kept by plant operators, the enforcement official should suggest that these type of records be kept on a daily basis.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of control equipment stack plumes and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust and if noted, determine point(s) of origin and require corrective action.

The enforcement official should complete the Inspector's Worksheet during his visit for future comparisons.

9. BASIC OXYGEN FURNACE

This is a major potential particulate emission source. Emissions are mainly a function of control system design and operation.

9.1 Process Description

Steel is produced by lowering the carbon, manganese, and silicon contents of iron by oxidation to levels desired for the type of steel required. Impurities such as sulfur and phosphorous are also lowered by using fluxes of appropriate composition. Steel scrap, flux, and hot metal are charged into a furnace lined with refractory material. The basic oxygen furnace process (BOF) is also known as oxygen-blown steelmaking. High purity oxygen (95 percent or better) is blown onto or into the molten metal bath in the furnace. There are three basic designs in use:

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DAILY REPORT OF OPEN HEARTH PRECIPITATOR (   )

Date ____________

HYDRAULIC COUPLING	1:00 A.M.	2:00 A.M.	3:00 A.M.	4:00 A.M.	5:00 A.M.	6:00 A.M.	7:00 A.M.	8:00 A.M.	9:00 A.M.	10:00 A.M.	11:00 A.M.	12:00 NOON	1:00 P.M.	2:00 P.M.	3:00 P.M.	4:00 P.M.	5:00 P.M.	6:00 P.M.	7:00 P.M.	8:00 P.M.	9:00 P.M.	10:00 P.M.	11:00 P.M.	12:00 MID
Oil Temp In																								
Oil Temp Out																								
Speed																								
Amperes																								
INLET RECTIFIER CONSOLE																								
Primary Current																								
Primary Voltage																								
Precip Current																								
CENTER RECTIFIER CONSOLE																								
Primary Current																								
Primary Voltage																								
Precip Current																								
OUTLET RECTIFIER CONSOLE																								
Primary Current																								
Primary Voltage																								
Precip. Current																								
HOT AIR BLOWERS																								
Pressure																								
Temperature																								
Oil Pressure N																								
Oil Pressure S																								

Remarks:

FIGURE 8.4 TYPICAL PRECIPITATOR MAINTENANCE RECORD

(1) the basic oxygen process, (2) the Stora-Kaldo process, and (3) the rotor process.

The BOF process was developed to full scale operations in the early 1950's at Linz-Donawitz, Austria, and is also known as the L-D process. The basic oxygen furnace is a pear-shaped steel shell, lined with refractory, in an upright position (Figure 9.1). The vessel is tilted for charging and tapping. Most of the installations in the United States are of this type. Sixteen steel companies have 34 of the 36 BOF installations in the United States (Table 9.1).

The basic BOF process consist of charging, blowing, metal testing, tapping and slagging. The charge is generally 25 to 35 percent scrap metal and 65 to 75 percent molten pig iron. The scrap is charged first and may be preheated by the combustion of natural gas introduced into the furnace by the lance. Charging is completed by the addition of flux and molten pig iron. Blowing is the introduction of oxygen into the molten charge through the lance. The amount of oxygen varies slightly and depends on the quantity of impurities. The oxygen combines with iron in an exothermic reaction. No additional fuel is required. Blowing is done at sonic velocity providing sufficient agitation of the molten charge to melt the scrap and provide good heat contact. The blowing lasts about 20 minutes, at which time the steel composition is determined. Additions and further blowing are determined by this analysis. When the desired composition is reached, the finished steel is tapped into ladles. Slag is tapped into a separate ladle. The complete cycle, called a heat, is then repeated.

Fumes and gaseous emissions emanate from the mouth of the vessel and enter a hood during the oxygen blow. Exhaust gases leave the hood and run through a series of water sprays before going to an air pollution device.

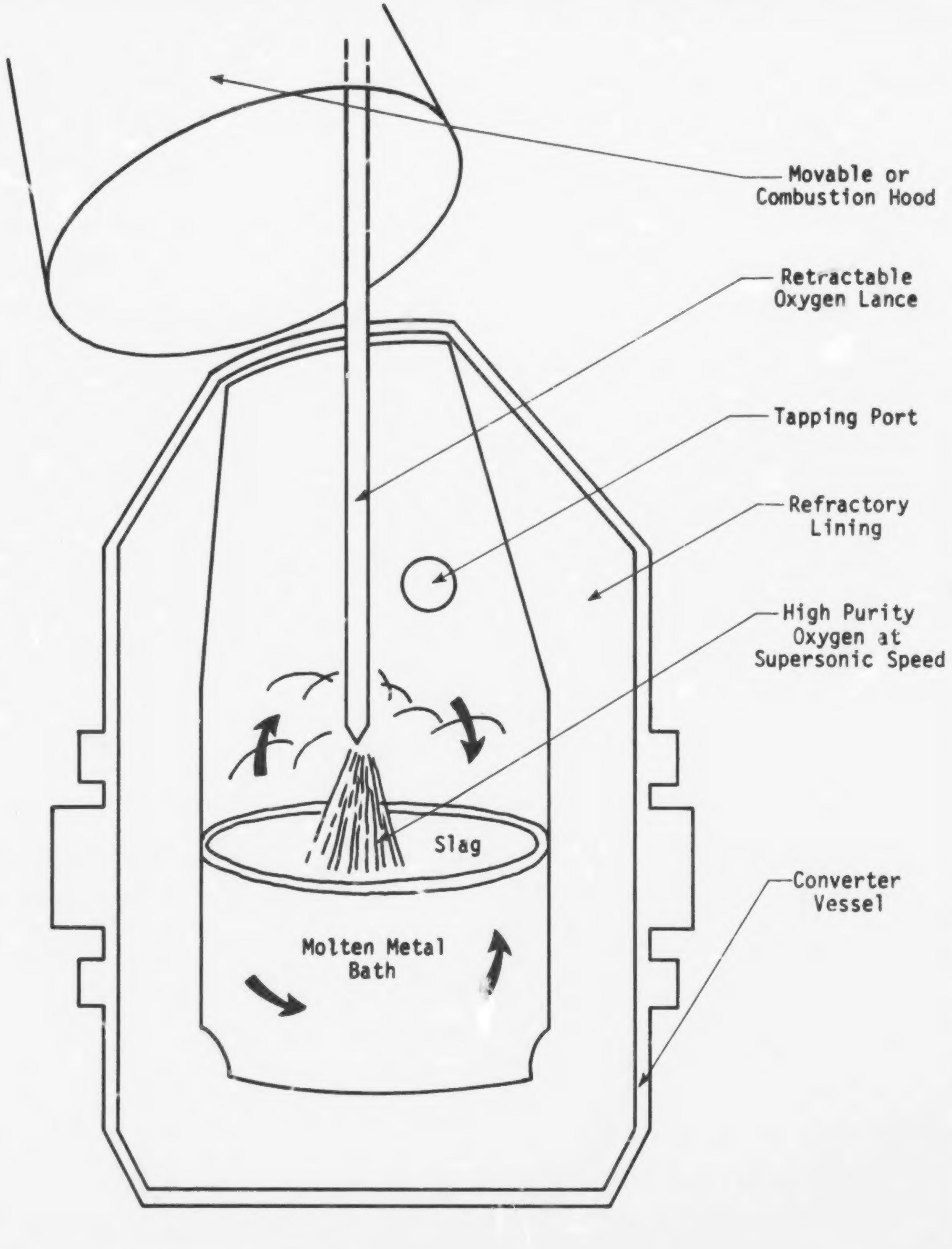

Movable or Combustion Hood
Retractable Oxygen Lance
Tapping Port
Refractory Lining
High Purity Oxygen at Supersonic Speed
Slag
Converter Vessel
Molten Metal Bath

FIGURE 9.1 BASIC OXYGEN FURNACE

TABLE 9.1 BASIC OXYGEN FURNACE INSTALLATIONS AND ASSOCIATED AIR POLLUTION CONTROL EQUIPMENT

		Number	Net Tons Per Heat	Annual Capacity (net tons) March 1969	Annual Capacity (net tons) Future	Start-up Date	Electrostatic Precipitator	High Energy Wet Scrubbers
Allan Wood Steel Co.	Conshohocken, Pa.	2	140	1,250,000		1968	X	
Allegheny-Ludlum Steel Corp.	Nattona, Pa.	2	80	500,000		1966		X
Armco Steel Corp.	Ashland, Ky.	2	160	1,400,000		1963	X	
	Middletown, Ohio	2	200		2,000,000	1969		X
Bethlehem Steel Corp.	Bethlehem, Pa.	2	250	2,500,000		1968	X	
	Burns Harbor, Ind.	2	250		1,800,000	1970		X
	Lackawanna, N.Y.	3	290	4,700,000		1964 - 66		X
	Sparrows Point, Md.	2	200	2,500,000		1966		X
CF & I Steel Corp.	Pueblo, Colo.	2	120	1,100,000		1961	X	
Crucible Steel Corp.	Midland, Pa.	2	90	1,250,000		1968		X
Ford Motor Co.	Dearborn, Mich.	2	250	2,500,000		1964	X	
Granite City Steel Co.	Granite City, Ill.	2	225	2,200,000		1967	X	
Inland Steel Co.	East Chicago, Ind.	2	255	3,000,000		1966		X
		2	210		2,000,000	1973		X
Interlake Steel Corp.	Chicago, Ill.	2	75	730,000		1959	X	
Jones & Laughlin Steel Corp.	Aliquippa, Pa.	2	80	1,000,000		1957	X	
		3	200	3,000,000		1968	X	
	Cleveland, Ohio	2	225	2,250,000		1961	X	
Kaiser Steel Corp.	Fontana, Calif.	3	110	1,440,000		1958	X	
McLouth Steel Corp.	Trenton, Mich.	2	110			1958	X	
		1	110	2,800,000		1960	X	
		2	110			1969	X	
National Steel Corp.								
Great Lakes Steel Div.	Ecourse, Mich.	2	300	3,500,000		1962	X	
		2	200		2,000,000	1970	X	
Weirton Steel Div.	Weirton, W. Va.	2	325	3,400,000		1967		X
Republic Steel Corp.	Buffalo, N.Y.	2	100		1,000,000	1970	X	
	Cleveland, Ohio	2	240	2,400,000		1966	X	
	Gadsden, Alabama	2	190	1,500,000		1965	X	
	Warren, Ohio	2	180	1,600,000		1965	X	
United States Steel Corp.	Braddock, Pa.	2	220		2,250,000	1972		X
	Duquesne, Pa.	2	215	2,400,000		1963		X
	Gary, Indiana	3	200	3,700,000		1965		X
	Lorain, Ohio	2	220		2,250,000	1970		X
	South Chicago, Ill.	3	150		3,000,000	1969		X
Wheeling-Pittsburgh Steel Corp.	Monessen, Pa.	2	200	1,500,000		1964	X	
	Steubenville, Ohio	2	250	2,000,000		1965		X
Wisconsin Steel Div.								
International Harvester Co.	South Chicago, Ill.	2	140	1,200,000		1964	X	
Youngstown Sheet & Tube Co.	East Chicago, Ill.	2	265		2,400,000	1969	X	
		Total		57,320,000	18,700,000		23	15

The temperature of the gases leaving the furnace is several thousand degrees and must be cooled before entering any air pollution control device. The fumes generally consist of fine reddish brown iron oxide and carbon monoxide. For combustion type hoods, the iron is oxidized to Fe_2O_3 while in shops using a movable hood, the iron is partially oxidized to FeO. The iron oxide particulate ranges from 0.01 to 10 microns for combustion hoods and 0.5 to 30 microns for movable hoods. Other emissions from the BOF occur during charging, fluxing, slagging, metal testing, and tapping. The vessel is tilted when charged with the scrap and, as a result, some visible particulate escapes the hood and passes to the roof monitors. The vessel is also tilted for charging of the molten iron. When the iron comes in contact with cool scrap material in the vessel, iron oxide and kish are emitted. Visible emissions occur during tapping and slagging. The hood over the vessel has little control over emissions when the vessel is tilted.

All BOF installations in the United States have air pollution control systems. Electrostatic precipitators or high energy venturi scrubbers are used.

A movable hood is one that is lowered securely over the mouth of the vessel during oxygen blowing. Because this hood is closer to the mouth, the required inspiration rate and exhaust flow volume are considerably less than that required for a combustion hood. The gases are rich in CO.

The hot gases must be cooled before going to the control equipment. Most BOF shops will have automatic hood and/or duct water spray systems which are activated at certain gas temperatures. Occasionally, the spray system cannot control the temperature so a bypass is placed in the exhaust stream. This would allow gases from the vessel to bypass the control device and be emitted directly to the atmosphere. If this occurs, a dense reddish brown plume goes to the atmosphere. BOF plants will usually have a slightly visible (less than 20 percent opacity) plume which can be seen about the time the oxygen lance is lowered and blowing initiated. A steam plume can be seen throughout the blow for units with high energy scrubbers. A CO flare may be seen at the top of the stack for plants which employ a movable hood.

9.2 Process Control Operation

The most important operating variable which affects emission levels is steel production rate.

Emissions occur mainly during the oxygen blowing period. The emissions from the BOF are governed by the oxygen blowing time and the oxygen blowing rate, major factors determining production rate. To a lesser degree, the ratio of molten iron to scrap and flux additives will also affect the quantity of particulate emissions. Different types of steel will require different amounts of oxygen. To produce low carbon steel, the oxygen usage is increased. Often after the hot metal is analyzed, a reblow, lasting several minutes, is necessary to achieve the desired structural properties.

The reladling station, where hot metal is received and transferred to BOF shop ladles, is a source of iron oxide and kish emissions. Many plants will hood this reladling station and clean the gases. Baghouses are normally used as control equipment. The major problem from the BOF steelmaking process is particulate matter. High energy venturi scrubbers and electrostatic precipitators have been used to reduce particulate emissions from BOF shops. Generally, the use of electrostatic precipitators is accompanied with a fixed hood and an inspiration flow rate of about 200,000 cfm. Depending on the availability of water and the secondary treatment that must accompany the water from scrubbers, high energy venturi units have also been used to clean exhaust gases from the BOF shop. Both of these types of control systems can reduce or nearly eliminate particulate emissions from the BOF shop if designed and operated correctly.

One of the factors which applies to either control device is the entering gas temperature. Cooling is required before the gases enter a precipitator or a venturi scrubber. This is usually accomplished with water sprays. This gas temperature to the precipitator is important in that the BOF dust resistivity is dependent upon that temperature.

There are several operational control features of an electrostatic precipitator which are important in cleaning particulate matter (Chapter 5). In order to attain good removal efficiency, all sections of the precipitator must be operating as designed.

Venturi scrubbers, Figure 9.2, have fewer operating control variables than a precipitator. Pressure drop is the principal variable as some venturi scrubbers may be equipped with variable throats. Chapter 36 of this manual discusses some of the important operating variables of various type scrubbers that could be used in BOF installations. To a lesser degree, water flow rate within the scrubber is important. Most steel plants will have monitoring systems that will record air flow rate, pressure drop, and water flow rate in a scrubber. The fan house for these scrubbing units generally have volt meters and ammeters. Many steel plants will have an opacity meter on the BOF stack as well as monitors in the duct for CO, HC, moisture, and temperature.

9.3 Enforcement Procedure

The objective of BOF shop operation inspection is to establish compliance with particulate and carbon monoxide emission regulations. In

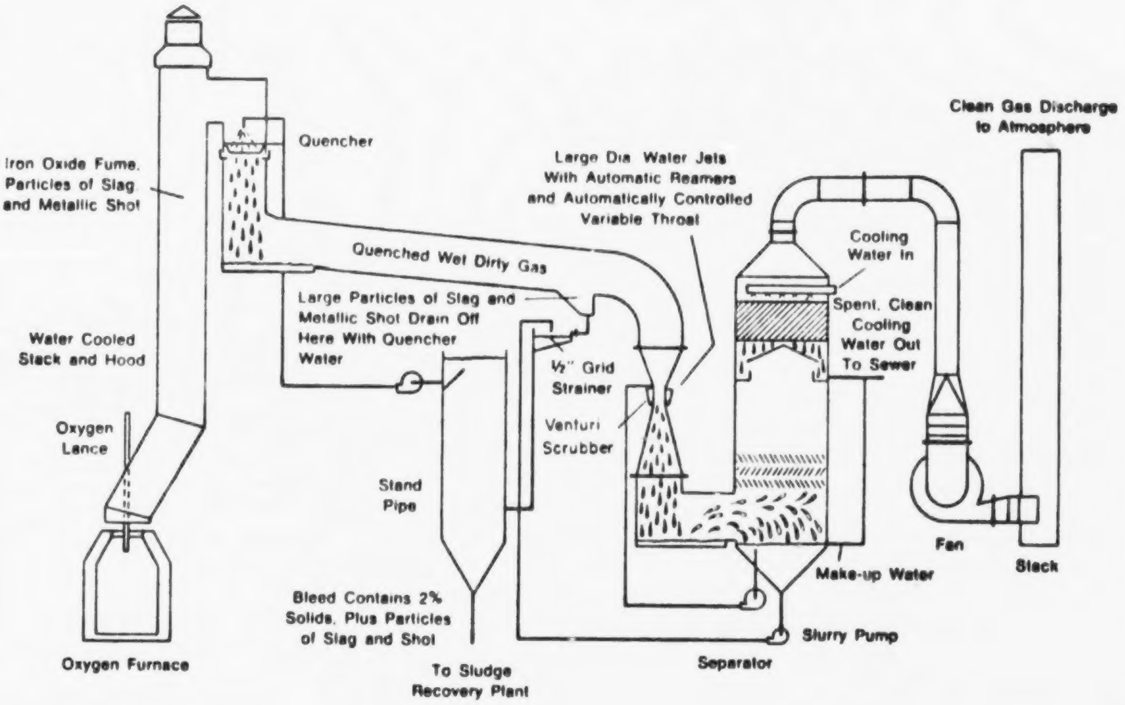

Clean Gas Discharge to Atmosphere
Quencher
Iron Oxide Fume, Particles of Slag and Metallic Shot
Large Dia. Water Jets With Automatic Reamers and Automatically Controlled Variable Throat
Cooling Water In
Quenched Wet Dirty Gas
Large Particles of Slag and Metallic Shot Drain Off Here With Quencher Water
Spent, Clean Cooling Water Out To Sewer
Water Cooled Stack and Hood
½" Grid Strainer
Oxygen Lance
Venturi Scrubber
Stand Pipe
Fan
Stack
Make-up Water
Bleed Contains 2% Solids, Plus Particles of Slag and Shot
Slurry Pump
Oxygen Furnace
To Sludge Recovery Plant
Separator

FIGURE 9.2 VENTURI SCRUBBER FOR BOF SHOP

order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and carbon monoxide emissions levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

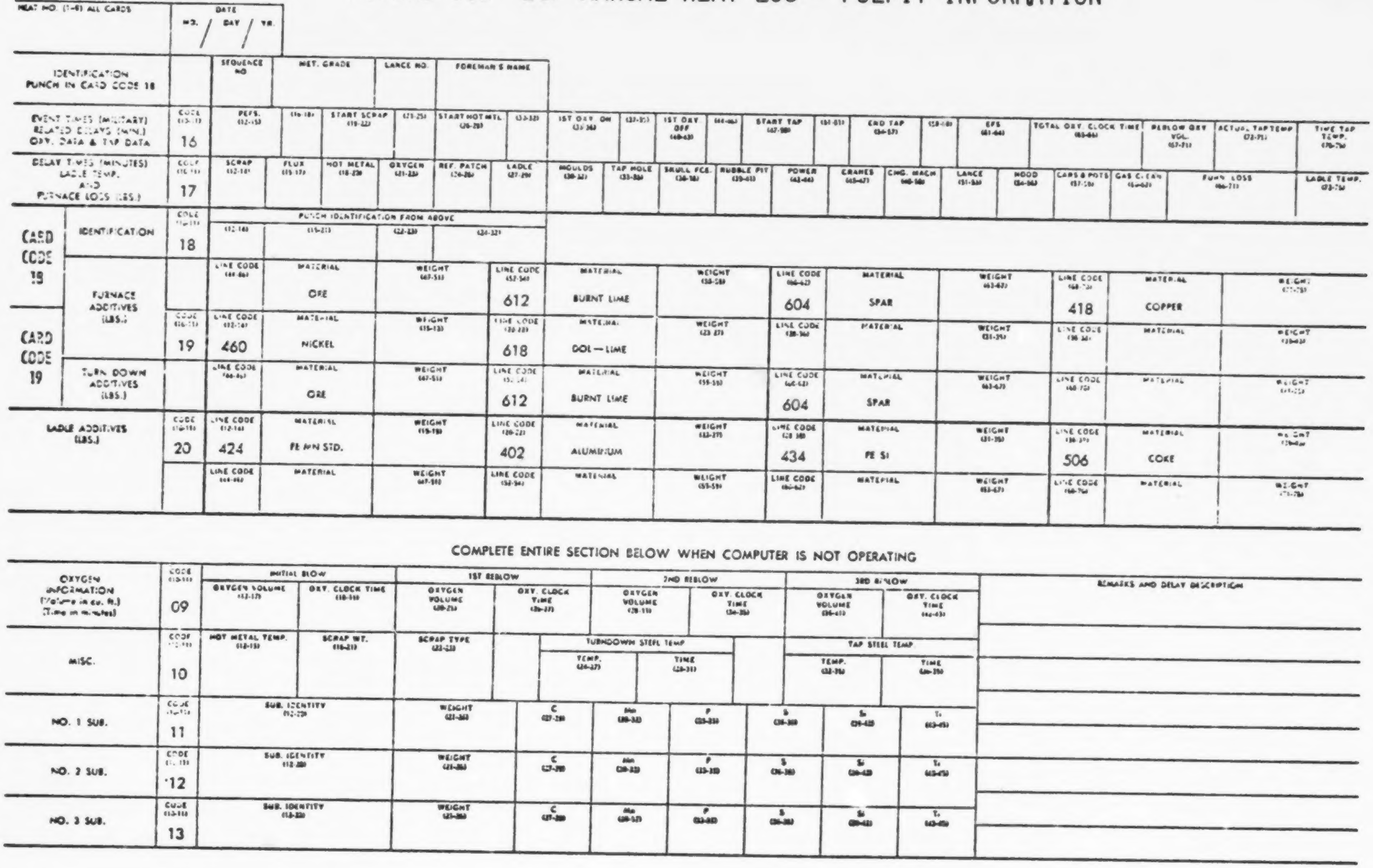
Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

The shop will have a control booth near the units for monitoring. The enforcement official should have little difficulty assessing the current operating status of the vessels by observing the many recorders, gauges and log sheets which are normally kept.

Emissions from a BOF installation depend on the operating condition of the control equipment. Part VI of this manual provides detailed analyses of the air pollution control devices.

The enforcement official should observe one complete heat cycle from tap to tap. Certain types of operational data should be recorded on the Inspector's Worksheet and, if possible, this data should be compared to other plant records for other heats to diagnose whether this is any unusual heat, especially with respect to capacity and 0_2 blow rate. Figure 9.3 is an example of the kinds of operating logs that are normally kept at BOF shops.

FIGURE 9.3 BOF MANUAL HEAT LOG - PULPIT INFORMATION



HEAT NO. (1-6) ALL CARDS	DATE MO. / DAY / YR.

IDENTIFICATION PUNCH IN CARD CODE 18		SEQUENCE NO	MET. GRADE	LANCE NO.	FOREMAN'S NAME

EVENT TIMES (MILITARY) RELATED DELAYS (MIN.) OXY. DATA & TAP DATA	CODE 16	PEFS. (12-15)	(16-18)	START SCRAP (19-22)	(23-25)	START HOT MTL. (26-29)	(30-32)	1ST OXY. ON (33-36)	(37-39)	1ST OXY. OFF (40-43)	(44-46)	START TAP (47-50)	(51-53)	END TAP (54-57)	(58-60)	EFS (61-64)	TOTAL OXY. CLOCK TIME (65-66)	REBLOW OXY VOL. (67-71)	ACTUAL TAP TEMP (72-75)	TIME TAP TEMP. (76-79)

DELAY TIMES (MINUTES) LADLE TEMP. AND FURNACE LOSS (LBS.)	CODE 17	SCRAP (12-14)	FLUX (15-17)	HOT METAL (18-20)	OXYGEN (21-23)	REF. PATCH (24-26)	LADLE (27-29)	MOULDS (30-32)	TAP HOLE (33-35)	SKULL PCS. (36-38)	RUBBLE PIT (39-41)	POWER (42-44)	CRANES (45-47)	CHG. MACH (48-50)	LANCE (51-53)	HOOD (54-56)	CARS & POTS (57-59)	GAS CLEAN (60-62)	FURN LOSS (66-71)	LADLE TEMP. (73-76)

CARD CODE 18	IDENTIFICATION	CODE 18	PUNCH IDENTIFICATION FROM ABOVE (12-14)	(15-21)	(22-23)	(24-32)

CARD CODE 19	FURNACE ADDITIVES (LBS.)		LINE CODE (44-46)	MATERIAL ORE	WEIGHT (47-51)	LINE CODE (52-54) 612	MATERIAL BURNT LIME	WEIGHT (55-59)	LINE CODE (60-62) 604	MATERIAL SPAR	WEIGHT (63-67)	LINE CODE (68-70) 418	MATERIAL COPPER	WEIGHT (71-75)
CARD CODE 19		CODE 19	LINE CODE (12-14) 460	MATERIAL NICKEL	WEIGHT (15-19)	LINE CODE (20-22) 618	MATERIAL DOL—LIME	WEIGHT (23-27)	LINE CODE (28-30)	MATERIAL	WEIGHT (31-35)	LINE CODE (36-38)	MATERIAL	WEIGHT (39-43)
	TURN DOWN ADDITIVES (LBS.)		LINE CODE (44-46)	MATERIAL ORE	WEIGHT (47-51)	LINE CODE (52-54) 612	MATERIAL BURNT LIME	WEIGHT (55-59)	LINE CODE (60-62) 604	MATERIAL SPAR	WEIGHT (63-67)	LINE CODE (68-70)	MATERIAL	WEIGHT (71-75)
LADLE ADDITIVES (LBS.)		CODE 20	LINE CODE (12-14) 424	MATERIAL FE MN STD.	WEIGHT (15-19)	LINE CODE (20-22) 402	MATERIAL ALUMINUM	WEIGHT (23-27)	LINE CODE (28-30) 434	MATERIAL FE SI	WEIGHT (31-35)	LINE CODE (36-38) 506	MATERIAL COKE	WEIGHT (39-43)
			LINE CODE (44-46)	MATERIAL	WEIGHT (47-51)	LINE CODE (52-54)	MATERIAL	WEIGHT (55-59)	LINE CODE (60-62)	MATERIAL	WEIGHT (63-67)	LINE CODE (68-70)	MATERIAL	WEIGHT (71-75)

COMPLETE ENTIRE SECTION BELOW WHEN COMPUTER IS NOT OPERATING

OXYGEN INFORMATION (Volume in cu. ft.) (Time in minutes)	CODE 09	INITIAL BLOW OXYGEN VOLUME (12-17)	INITIAL BLOW OXY. CLOCK TIME (18-19)	1ST REBLOW OXYGEN VOLUME (20-25)	1ST REBLOW OXY. CLOCK TIME (26-27)	2ND REBLOW OXYGEN VOLUME (28-33)	2ND REBLOW OXY. CLOCK TIME (34-35)	3RD REBLOW OXYGEN VOLUME (36-41)	3RD REBLOW OXY. CLOCK TIME (42-43)	REMARKS AND DELAY DESCRIPTION

MISC.	CODE 10	HOT METAL TEMP. (12-15)	SCRAP WT. (16-21)	SCRAP TYPE (22-23)		TURNDOWN STEEL TEMP TEMP. (24-27)	TURNDOWN STEEL TEMP TIME (28-31)		TAP STEEL TEMP. TEMP. (32-35)	TAP STEEL TEMP. TIME (36-39)	
NO. 1 SUB.	CODE 11	SUB. IDENTITY (12-20)		WEIGHT (21-26)	C (27-28)	Mn (29-32)	P (33-35)	S (36-38)	Si (39-42)	Ti (43-45)	
NO. 2 SUB.	CODE 12	SUB. IDENTITY (12-20)		WEIGHT (21-26)	C (27-28)	Mn (29-32)	P (33-35)	S (36-38)	Si (39-42)	Ti (43-45)	
NO. 3 SUB.	CODE 13	SUB. IDENTITY (12-20)		WEIGHT (21-26)	C (27-28)	Mn (29-32)	P (33-35)	S (36-38)	Si (39-42)	Ti (43-45)	

INSPECTORS WORKSHEET

FOR STEEL PLANTS

GENERAL

Plant Id.____

Date of this Inspection_______________Date of last Inspection_______________

Type Furnace: Open Hearth, BOF, Electric Arc____________________

OPERATING VARIABLES

Steel Production Rate_________tons/heat

No. of Heats per day__________

No. of Furnaces Operating___ ____

This Heat: pounds of scrap metal_________, pounds of hot metal______________

Oxygen Blow______________scf/heat

Total Oxygen Clock Time__________min.

Spar Addition Rate__________________lbs/heat

ABATEMENT EQUIPMENT

Parameter \ Unit	1	2	3	4	Average in Industry
Particulate Efficiency (%)					95+%
Scrubber Pressure Drop (in. H_2O)					60+
Scrubber Water Flow Rate $\left(\frac{\text{gpm}}{\text{1000 scfm}}\right)$					5 to 10
Precipitation Spark Rate, (spm)					50 to 400
Primary Voltage					20 to 100 kv
Primary Amps					1
Flow Rate, (scfm)					30,000 to 300,000
Inlet temp, (^{o}F)					300^{o}
Opacity or Ringlemann No.					0

ACTUAL EMISSION DATA

Particulates__________________lb/ton of Steel Produced

Sulfur Dioxide________________lb/ton

CO____________________________lb/ton

Fluorides_____________________lb/ton

Tested by:__________________

Date:__________________

GENERAL OBSERVATIONS

Plume Capture______________________________________

Scrap and Hot Metal Addition________________________

Pouring____

Duct Work____

Age of Control Equipment___________years

Time In________________ Time Out________________

The enforcement official should make a visual inspection of the BOF vessel with the purpose of assessing the adequacy of the collection system. For movable type hoods it is necessary that the hood come in close proximity to the mouth of the vessel. Otherwise dense smoke may emanate from the vessel and escape the hood, especially during the first part of the blow. For fixed hoods, a check should be made to determine whether or not the inspiration flow rate is adequate. If any plume escapes the hood, it may be an indication that the collection system is undersized, the fans are not operating, there is a leak in the duct work, ducts are clogged, etc.

It is not only important that the control equipment be operating correctly during the inspector's visit, but operating continuously. The routine maintenance of control equipment should be verified as for effective air pollution control, it is mandatory that BOF operators carry out a regular maintenance program.

Since air pollution emissions depend primarily on the abatement equipment, the enforcement official should spend most of his time assessing the operating condition of the air pollution control devices.

Visible emissions are the simplest means for estimating particulate control equipment performance and the enforcement official should estimate the percent opacity of control equipment stack plumes. If in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust and if noted, determine point(s) of origin and require corrective actions.

10. ELECTRIC FURNACE

This is a major potential particulate emission source. Emissions are mainly a function of control system design and operation.

10.1 Process Description

There are approximately 200 electric arc steelmaking furnaces in the United States having a combined capacity of about 20 million tons per year. The size of furnaces vary from a few tons per heat up to 400 tons per heat. These furnaces are refractory lined cylindrical vessels with a top diameter of up to 22 feet (Figure 10.1).

The major component of the charge is steel scrap (Figure 10.2). Other ingredients charged to the furnace include alloying compounds, fluxes and coke breeze. Basically, there are two types of furnaces: movable roof (top charging) and fixed roof (door charging). The top charging furnace permits more rapid charging of scrap, while the side door charging furnace provides better fume control and improved refractory life. An oxygen lance is used in the electric furnace to increase production rate. The chemistry involved in this steelmaking process is the same as that for the open hearth and the BOF processes. Electric furnaces derive heat from electrical energy. The scrap is usually segregated by type for the production of special steels. Scrap is usually classified as clean or dirty scrap, depending on the rust and combustible content. More particulate emissions occur with the dirty scrap than the clean scrap.

Scrap may be preheated prior to charging into the furnace. Melt time is reduced with heated scrap. Emissions from scrap preheaters are not generally controlled by air pollution control systems.

The scrap is charged to the furnace using an overhead crane. Visible emissions are generated during charging. In terms of emissions, the type of scrap charged is quite important. The inclusion of large quantities of low boiling point non-ferrous metallic impurities will lead to high particulate concentrations in the fume. Oil and grease on the scrap will burn

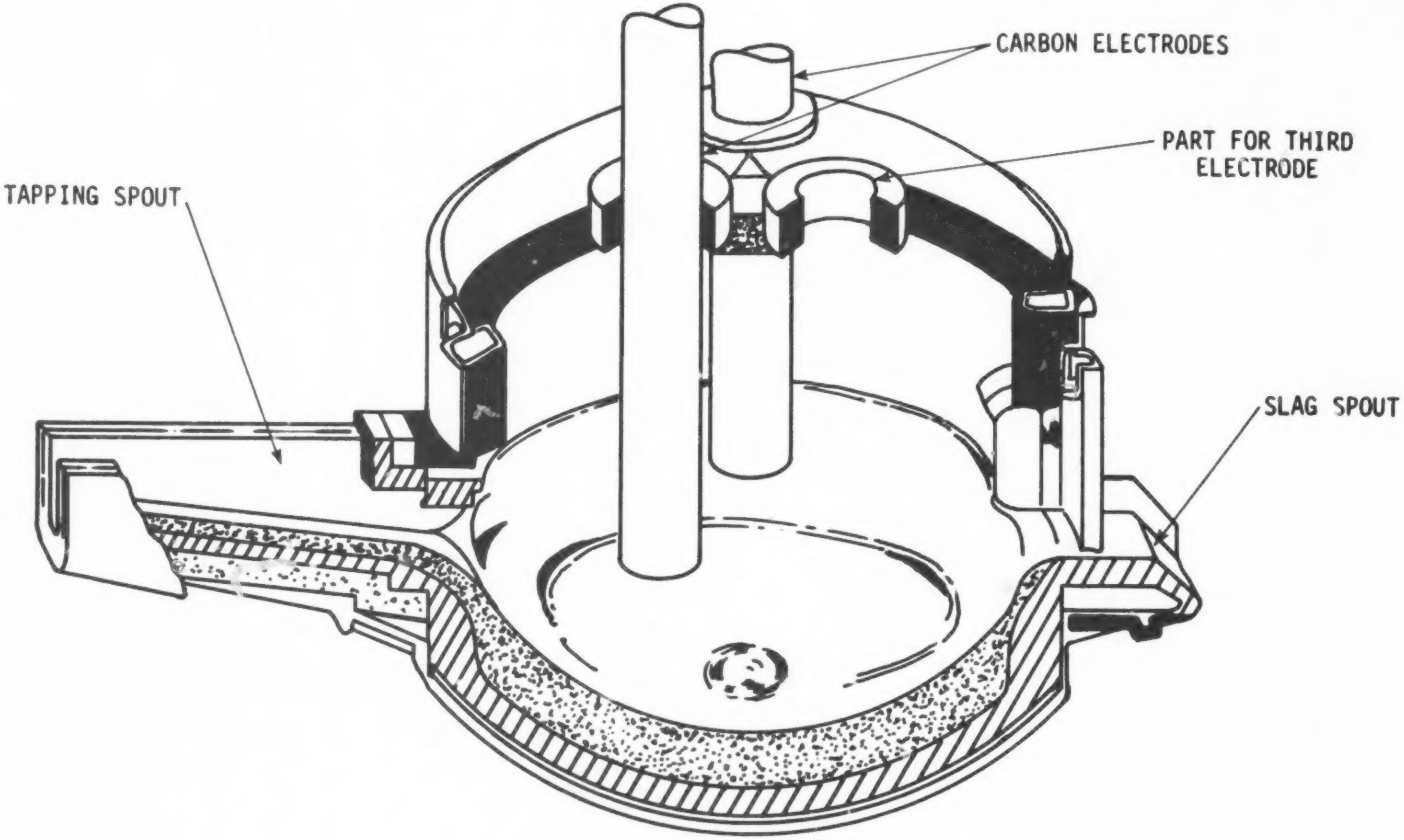

CARBON ELECTRODES
PART FOR THIRD ELECTRODE
TAPPING SPOUT
SLAG SPOUT

FIGURE 10.1 ELECTRIC FURNACE

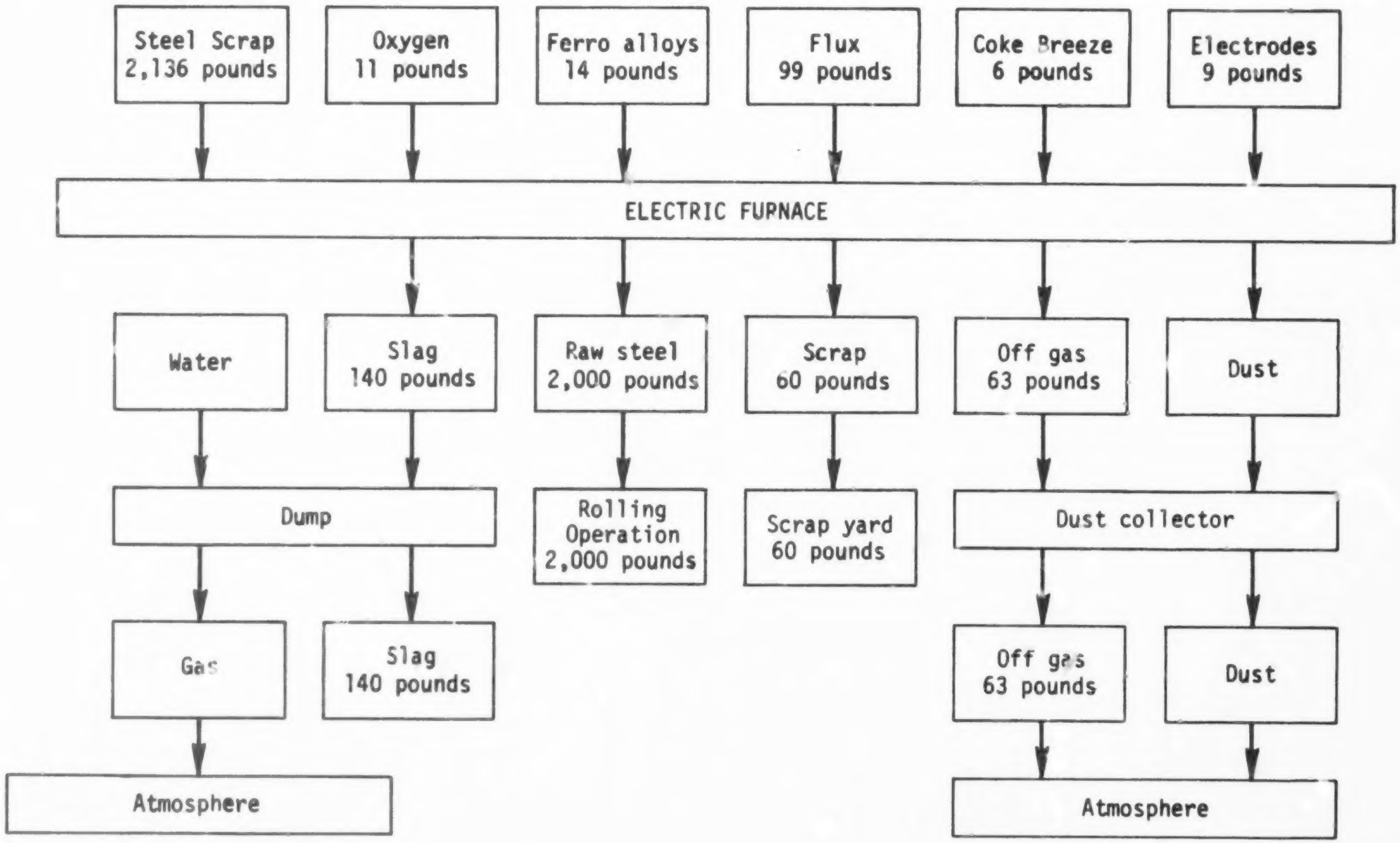

Steel Scrap
2,136 pounds
Oxygen
11 pounds
Ferro alloys
14 pounds
Flux
99 pounds
Coke Breeze
6 pounds
Electrodes
9 pounds
ELECTRIC FURNACE
Water
Slag
140 pounds
Raw steel
2,000 pounds
Scrap
60 pounds
Off gas
63 pounds
Dust
Dump
Rolling
Operation
2,000 pounds
Scrap yard
60 pounds
Dust collector
Gas
Slag
140 pounds
Off gas
63 pounds
Dust
Atmosphere
Atmosphere

FIGURE 10.2 EXAMPLE OF ELECTRIC FURNACE STEELMAKING USING A CHARGE OF COLD STEEL SCRAP (OXYGEN PRACTICE)

off at relatively low temperatures and result in significant amounts of carbonaceous particulate matter. Most of the fume generated during the melt cycle is Fe_2O_3. Other significant fume constituents include oxides of the alloys and deoxidizers. The dust is reddish-orange in color.

10.2 Process Control Operation

The process variables which affect emissions are:

1. Quality of the scrap,
2. Oxygen lancing,
3. Steel production rate.

The highest emissions will be encountered when dirty scrap is used. Oxygen lancing reduces heat time and increases particulate emissions. The weight of material charged to the furnace (process weight) is recorded in the operator's daily log.

For the relatively few fixed roof electric furnaces, emission control is accomplished by evacuation of the furnace shell. Tapping will cause some emissions which may be hooded and exhausted to the dust collector.

For the movable roof furnaces, the most common type, capture of charging fumes presents a major engineering control task. Several electric furnace shops have totally enclosed the building and evacuate to dust collectors through the roof monitor. While air volumes are large, this approach captures fumes from tapping, charging and any other particulate-generating operations in the shop.

In many cases there will be some type of evacuation of fumes from the furnace shell during the melt. One system is shown in Figure 10.3.

Baghouses, electrostatic precipitators and high energy wet scrubbers have been used at electric furnaces. Particulate emissions range from

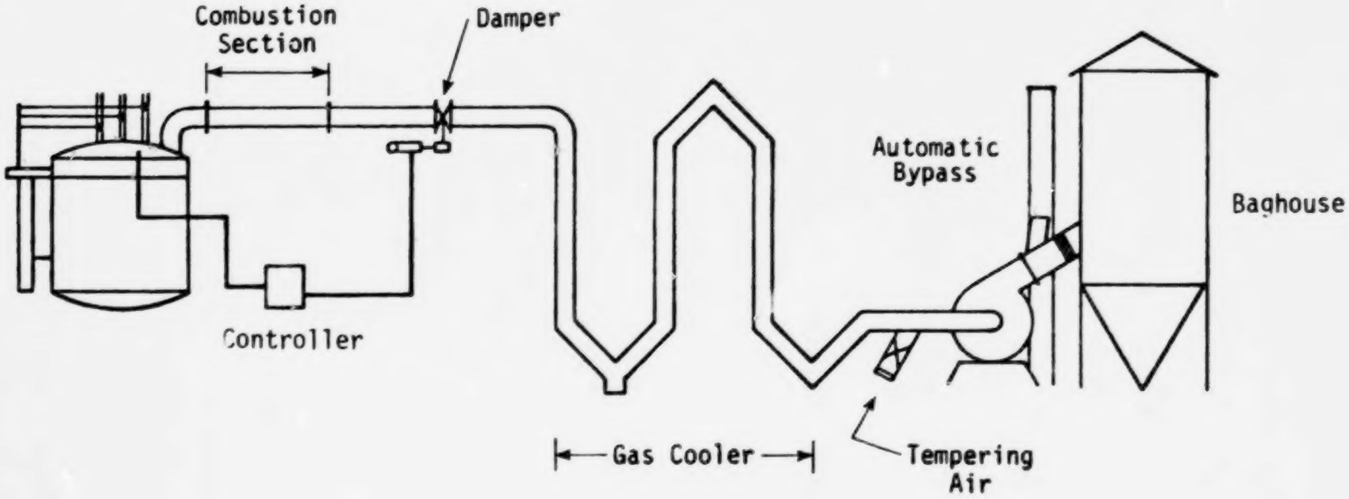

Combustion Section
Damper
Controller
Gas Cooler
Automatic Bypass
Tempering Air
Baghouse

FIGURE 10.3 ELECTRIC FURNACE CONTROL SYSTEM

10 to 40 pounds per ton, depending principally on the cleanliness of the scrap.

An operating variable which affects air pollution control equipment is the inlet temperature to the abatement unit. The gases leave the furnace at an elevated temperature and are cooled either through heat exchangers, air dilution or water sprays. Most baghouses will have a bypass system to prevent hot gases from destroying the bags. The most common bag fabric used in electric arc furnace installations are made of Dacron.® Other synthetic fibers have also been used. Fabric bags are not common because fluorspar, when used as a flux, generates fluoride gases which may deteriorate the bags. Electrostatic precipitators are uncommon at electric arc furnaces. Dust resistivity is unfavorable and the varying gas volume is difficult to handle.

10.3 Enforcement Procedure

The objective of electric steel shop operation inspections is to establish compliance with particulate emission regulations. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to plant inspection.

Production levels and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

The shop may have a control booth near the units for monitoring. The enforcement official should have little difficulty assessing the current operating status of the furnaces by observing the many recorders, gauges and logs which are normally kept.

The enforcement official should observe the electric furnace during charging, oxygen lancing and pouring. During oxygen blowing, air pollution emissions are expected to be the highest. If the control system including the ducts and hoods have been adequately designed, no plume should escape the hood. For those plants which capture fumes at the roof monitor there should be no visible emissions from the building. The capture system is the most important aspect of controlling air pollution from the electric arc steelmaking process.

The enforcement official should complete the Inspectors Worksheet for electric furnaces as the data on that sheet can be used as a comparison of the operating variables from inspection to inspection. As usual, the enforcement official should verify that the ducts, fans, and abatement equipment are maintained regularly and are functioning properly.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement officer should estimate the percent opacity of control equipment stack plumes and, if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust and, if noted, determine point(s) of origin and require corrective action.

INSPECTORS WORKSHEET

FOR STEEL PLANTS

GENERAL

Plant Id. ____

Date of this Inspection ______________ Date of last Inspection ________________

Type Furnace: Open Hearth, BOF, Electric Arc ______________________

OPERATING VARIABLES

Steel Production Rate __________ tons/heat

No. of Heats per day __________

No. of Furnaces Operating __________

This Heat: pounds of scrap metal __________, pounds of hot metal ______________

Oxygen Blow ______________ scf/heat

Total Oxygen Clock Time __________ min.

Spar Addition Rate ______________ lbs/heat

ABATEMENT EQUIPMENT

Unit Parameter	1	2	3	4	Average in Industry
Particulate Efficiency (%)					95+%
Scrubber Pressure Drop (in. H_2O)					60+
Scrubber Water Flow Rate $\left(\frac{\text{gpm}}{\text{1000 scfm}}\right)$					5 to 10
Precipitation Spark Rate, (spm)					50 to 400
Primary Voltage					20 to 100 kv
Primary Amps					1
Flow Rate, (scfm)					30,000 to 300,000
Inlet temp, (^oF)					300^o
Opacity or Ringlemann No.					0

ACTUAL EMISSION DATA

Particulates___________________lb/ton of Steel Produced

Sulfur dioxide_________________lb/ton

Carbon monoxide________________lb/ton

Fluorides______________________lb/ton

Tested by:____________________

Date:__________________________

GENERAL OBSERVATIONS

Plume Capture____

Scrap and Hot Metal Addition____

Pouring____

Duct Work____

Age of Control Equipment____________years

Time In____________________ Time out__________________

11. STEEL SHAPING AND FINISHING

In general, emission potential from these operations is minimal in comparison to other steel plant operations.

11.1 Process Description

Following the refining operation at the steelmaking furnaces the steel is converted to semi-finished shapes before manufacturing into finished products. The two principal methods of converting the molten steel into semi-finished products are ingot casting followed by rolling, and continuous casting.

The major portion of the steel produced in this country is teemed (poured) into large cast iron molds (Figure 11.1). Upon solidification these steel castings are called "ingots". After removal from the molds the ingots are placed in furnaces called "soaking pits" (Figure 11.2). The soaking pit heats the ingot to a uniform temperature to facilitate rolling. The hot ingots are then transported to the roughing mill (Figure 11.3), where they are rolled into billets, blooms, or slabs for subsequent processing into finished products. Billets are normally 2 to 5 inches square while blooms are square or slightly oblong shapes 6 to 12 inches on a side. Slabs are oblong, generally between 2 and 9 inches thick and 24 to 60 inches wide. All the shapes have rounded corners and dimensions are approximate.

Continuous casting of steel is a relatively new process that eliminates much of the handling necessary in ingot casting. In continuous casting (Figure 11.4), the molten steel is transported from the furnace in a ladle and poured into a water-cooled bottomless mold. The metal cools quickly to the shape of the mold and the solidified steel is extracted from the bottom of the mold continuously in one or several strands.

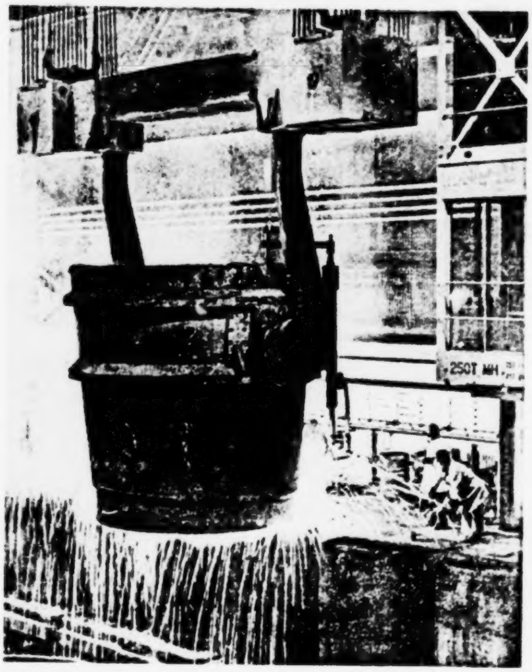


FIGURE 11.1 TEEMING OF INGOTS

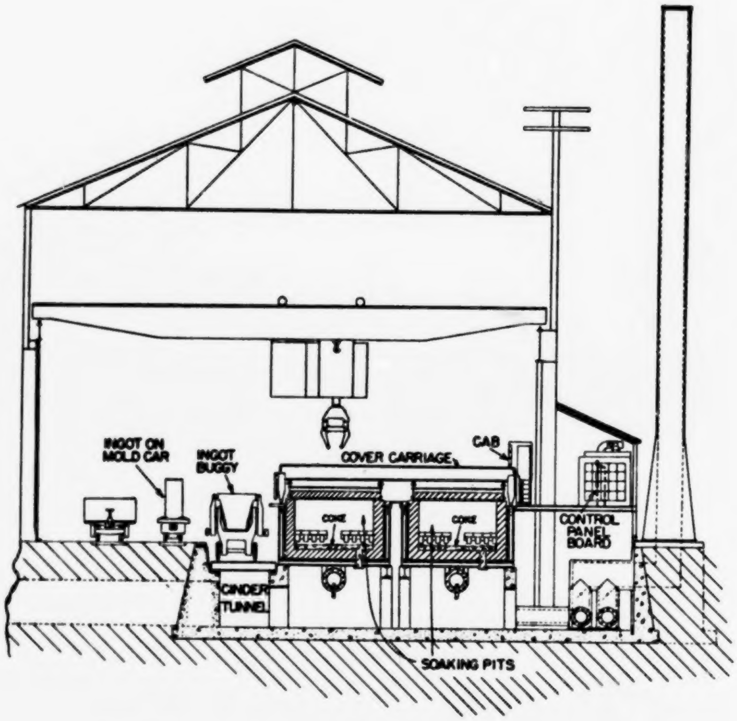

INGOT ON MOLD CAR
INGOT BUGGY
COVER CARRIAGE
CAB
COKE
COKE
CONTROL PANEL BOARD
CINDER TUNNEL
SOAKING PITS

FIGURE 11.2 SOAKING PITS

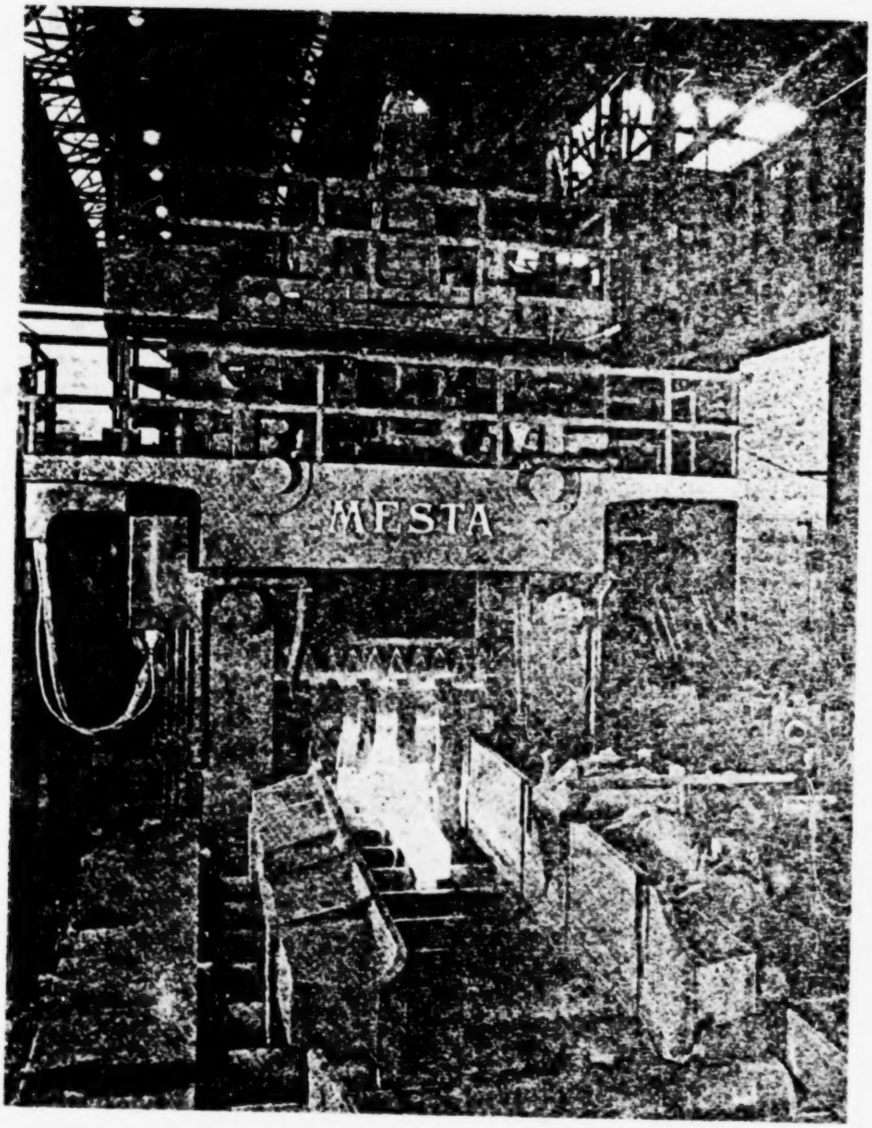


FIGURE 11.3 ROUGHING MILL

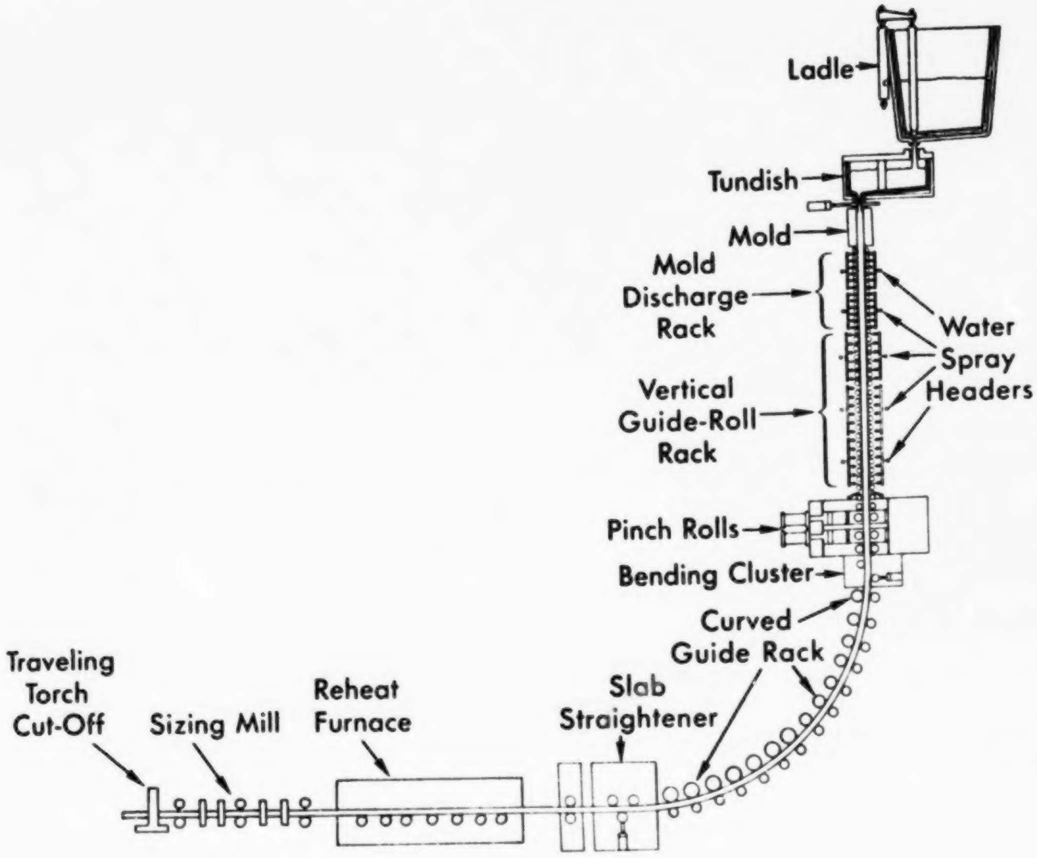

Ladle
Tundish
Mold
Mold Discharge Rack
Water Spray Headers
Vertical Guide-Roll Rack
Pinch Rolls
Bending Cluster
Curved Guide Rack
Traveling Torch Cut-Off
Sizing Mill
Reheat Furnace
Slab Straightener

FIGURE 11.4 CONTINUOUS CASTING

The cast bar is cut to a predetermined length for further processing. Continuous casting machines can produce billets, blooms, or slabs depending on the final products of the plant.

Prior to forming into final shapes, the billets, blooms, and slabs are gound, chipped or scarfed to remove surface defects. Grinding and chipping are hand operations. Scarfing removes surface defects by burning. It can be either a hand or machine operation. In hand scarfing the defect is spot-heated by a fuel-oxygen torch, speeded by use of a starting rod.

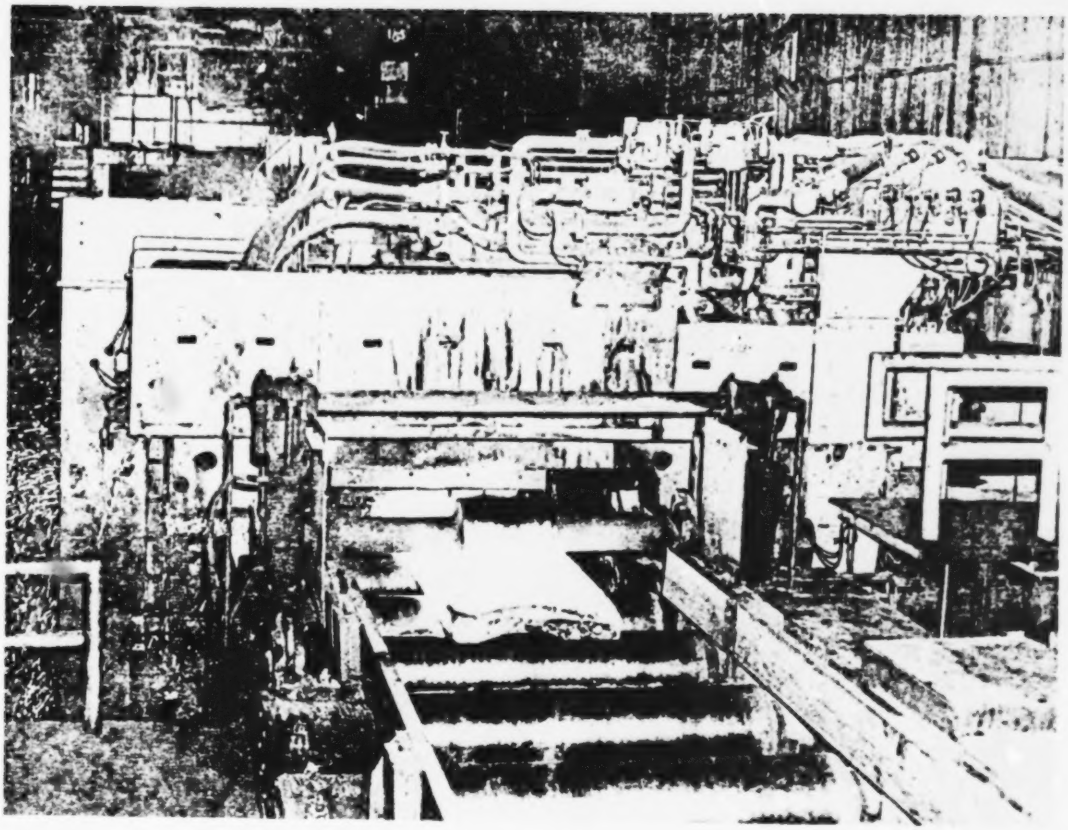


FIGURE 11.5 HOT SCARFING MACHINE

Once the reaction has started, the heat of oxidation is sufficient to continue the reaction so fuel is no longer needed. Mechanical scarfing uses rows of torches to burn all the surfaces of the steel slab as it passes through the machine. The scarfer (Figure 11.5), is usually directly in the mill line so that the steel is at a sufficiently high temperature to eliminate the need for starting rods. The hot scarfing machine removes a thin layer (one-eighth or less) of metal.

After conditioning, the billets, blooms, or slabs are soaked (heated) in reheat furnaces. When the required uniform temperature is reached, the semi-finished products are taken to the hot rolling mills where they are processed into rods, bars, angles, pipe, channels, plate, sheet, or strip. These are finished products in most cases.

Sheet and strip steel can be further processed by cold rolling. A pickling operation is the first step in this process. Sulfuric or hydrochloric acid treatment cleans the oxidized surface formed during the hot rolling. The steel can be bath-dipped or passed continuously through this bath.

Annealing of sheet or strip is a heat treating operation to improve the strength characteristics of the steel. This is accomplished in either a batch or continuous furnace. In the batch operation the coiled steel is enclosed in a removable shell. The shell is heated by combustion gases while an inert or protective atmosphere inside the shell prevents oxidation of the steel coil. In the continuous process the steel passes through an annealing furnace. The heating, holding, and cooling sections of the furnace have a controlled atmosphere to prevent oxidation.

The final step in the production of a small percentage of the steel industry's products is surface coating. These coatings include zinc, tin, terne (lead alloy), aluminum, chromium, nickel, copper, phosphate and a broad spectrum of paints and other organic materials. Prior to coating, the continuous strip is cleaned with a hot alkaline solution or heated to remove grease or oil films. The lightly oxidized surface then is acid-cleaned or annealed.

Zinc, aluminum, and terne coat are applied by a dip coating process. The preheated strip is treated with a flux or passed through a flux layer on top of the metal bath. Electrolytic processes can be employed to surface-coat the steel with zinc, chromium, nickel, or copper. In this operation, clean strip enters directly into the particular plating bath. Another process for coating with chromium or nickel involves coating the steel with a chemical solution of the desired material. The solution coating is then reduced in a hydrogen atmosphere to produce the final metal coating.

Phosphate coatings are accomplished by dipping the steel in a dilute acid-phosphate solution which is saturated with a metal such as zinc, cadmium, aluminum, or lead. This results in the metal surface being converted into an insoluble crystalline phosphate coating.

An electrocoating (electrophoretic deposition) process is one method employed to apply paint to the steel surface. This is accomplished in either a dip tank or by roller coating. An electrical charge is applied to a solution of paint in water which causes the paint resins to move to the oppositely charged steel immersed in the solution. After washing, the paint coating is baked. Spray or dip coating with solvent-based paints is more common than electrocoating.

11.2 Process Control Operation

Minor amounts of iron oxide fume are generated when the molten steel is poured into the ingot molds. The coating applied to the inner surfaces of the ingot mold to reduce surface imperfections of the steel casting is the primary source of emissions. One general type of mold coating is nonvolatile, relying on surface texture to accomplish the desired surface improvement. The other general type of coating relies on volatilization to shield against metal splashing. This type includes coal-tar products and petroleum derivatives resulting in carbonaceous gas emissions.

Pouring is done in a large area of the shop floor and emission controls are normally not used. In some cases where free-machining steel is being produced, lead is added to the steel during pouring resulting in the generation of lead oxide fumes. Where leaded steel is produced, ventilation systems for fume collection are usually provided because lead fumes present a potential employee health hazard.

Emissions generated during the pouring of ingots varies at each plant depending on the particular practice. Visible amounts of particulate emissions range from light to heavy. Where entire furnace shops are ventilated through the roof monitor, as in some electric furnace shops, emissions may be controlled by a baghouse.

Emissions during continuous casting are markedly lower than when teeming ingot molds. Continuous casting is done at a single location as opposed to the large area necessary for ingots. This allows for the efficient use of a localized fume-collecting system. The pouring tundish may be enveloped with a reducing gas to minimize oxidation of the steel. Mold lubricants are used to prevent seizure and result in a small amount of smoke. Some operations use torch cut-off machines which generate minor to moderate amounts of iron oxide particulates, depending on the amount of material cut. Where shears are used there are no air pollutant emissions.

Hand grinding, chipping, and scarfing result in small amounts of localized particulate emissions. Usually no emission controls are utilized except where shop practice calls for extensive amounts of grinding or hand scarfing and then collection hoods might be used. Particulate emissions from machine scarfing are substantial and usually are controlled with electrostatic precipitators or high energy scrubbers. About 50 percent of all hot rolled steel is surface conditioned by machine scarfing. Emissions are iron oxide fumes and would present a visible emission source if a control system were not employed.

Emissions from soaking pits or reheat furnaces are the normal producst of combustion. The furnaces are often fired with relatively clean blast furnace gas. In some cases natural gas or oil are used as the fuel. Carbon dioxide, trace quantities of carbon monoxide, and low concentrations of nitrogen oxides are present as in all combustion products. If any sulfur is present in the fuel, sulfur dioxide emissions will also be present. Induction heating of the steel billets, blooms, or slabs is used.

The iron oxide scale formed on the steel during reheating is broken off by high pressure water sprays as the steel enters the first rolling stand. Some quantities of fine iron oxide are generated at the strip finishing stands. At some mills these emissions are collected and controlled with high-energy scrubbers.

The major potential emissions from cold working and surface treating are from cleaning operations which prepare the surface of hot rolled strip for cold rolling. The pickling operation provides the metal with a clean surface for cold rolling. A sulfuric or hydrochloric acid bath is maintained in the pickling tank. The tanks are generally hooded and exhausted to a fume control system. Wet scrubbers or packed towers are used to remove acid mist from the exhaust air. In some cases where only small quantities of steel are pickled, the exhaust may be vented directly to the atmosphere.

Cold rolling is accomplished by high speed rolls. Emissions from this operation consist of small amounts of water-oil mist which is generated by the roll lubricant. Mechanical mist eliminators or wet scrubbers are used to collect these emissions.

Surface coating of steel for protection and appearance is tending toward continuous-line operation for economic reasons. Emission controls are also easier to apply to continuous lines. Prior to galvanizing, cold rolled steel is heat-treated. The galvanizing pot is covered with a flux which generates some emissions as the steel passes through it. This flux may be ammonium chloride or zinc ammonium chloride. Particulate emissions tend to agglomerate, causing gum in the ductwork. Control of these emissions is accomplished by a baghouse or wet scrubber.

Coating installations for the application of other metals, paints and plastics are essentially the same as already discussed.

Vapors from electroplating baths are collected by hoods and treated like the acid vapors from pickling.

Solvent vapors are emitted from painting operations. These are generally collected in an exhaust system and in most cases vented to the atmosphere outside the plant building. Some of the vapors evolved during the baking of painted surfaces are combusted in direct-fired ovens. The remainder are vented.

11.3 Enforcement Procedure

The objective of steel-shaping and finishing operation inspection is principally to establish compliance with particulate emission regulations.

In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled emissions levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels, feed weight rates and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

Become familiar with the processes and where the control equipment is applied and make a visual inspection of the complete process. Follow the flow of material from casting to final product for each of the plant's product lines. Become familiar with the process operation at each station. While following the product flow, points of visible emissions should be noted and, if possible, identified. Check control equipment locations against the points of observed emissions to determine if any controls are not operating or are only partially effective.

Observe all collection hoods, especially at the hot scarfing machine, to determine if the collection rate is sufficient to capture the generated emissions. If a significant amount of dust is escaping it is an indication of an inefficiently operating or under-designed collection system. Take special notice of the collection hoods at the pickling tank and note any escaping fume or badly corroded ducts allowing fume leakage.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of control equipment stack plumes and, if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust and if noted, determine point(s) of origin and require corrective action.

12. SLAG

Hydrogen sulfide and particulate emissions are possible. Hydrogen sulfide is the principal pollutant.

12.1 Process Description

Slag is a by-product of the blast furnace and the steelmaking processes. The quantitites, properties, and end uses of these two types of slag are quite different. Blast furnace or iron slag is the dominant factor, accounting for 24.8 million of the 33.3 million tons of slag produced in the United States in 1971.

The two air pollution factors to be considered in slag processing are dust and sulfur gases. Blast furnace slag has an average sulfur content of about 1.8 percent, while steel slag averages about 0.1 percent sulfur. Table 12.1 shows a gross sulfur balance for the steel industry based on 1967 data, and puts the importance of slag as a sulfur disposal point in the steelmaking process in perspective.

The combined chemical form of the sulfur in cold blast furnace slag is permanently bound in non-reative forms. Sulfur emissions from slag are associated with the processes used to cool the slag from its original temperature of about 2,700°F.

Table 12.1 ANNUAL U. S. STEEL INDUSTRY SULFUR BALANCE (1967)

Sulfur In		
Coal to:	Coke Oven Gas	196,000
	Coke	455,000
	Coke Plant (Other)	69,000
		720,000
Fuel Oil		90,000
Ore		93,000
Scrap		20,000
Fluxes		21,000
Other		11,000
		955,000
Sulfur Out		
Blast Furnace Slag		518,000
Steel and Scrap		39,000
Steel Slag		14,000
Fuels		374,000
Other		10,000
		955,000 Tons

There are three types of slag, each manufactured by a different process. These are air cooled, granulated, and expanded slag. Granulated and expanded slag are produced only from blast furnace slag. All steel slag is air cooled.

12.1.1 Air Cooling

Air cooling of blast furnace slag accounts for two-thirds of the total slag production. It is the single most important individual process.

Molten slag is poured into pits or diked areas to solidify. Once cooled, it is removed by power machinery. The slag can be sold as is, or it can be crushed and screened to desired aggregate sizes.

While some steel plants operate their own slag plant, it is common for the molten slag to be sold to an independent operator whose facility is usually located on steel plant property. The supply of molten slag is controlled by the steel plant as blast furnace or steel furnace production is paramount. The slag plant gets slag as it is produced. Slag ladles are transported by a plant-operated railroad system to a slag processing area some distance from the furnace. Delays in transit cause freezing of a "skull" of slag on the sides and surface of the ladle, making it difficult to remove the slag; therefore, if the supply of slag ladles at the furnaces is short, slag plant operators will have to pour rapidly to prevent delays at the furnaces.

Because of limited space and time, water sprays may have to be applied to partially cooled slag to accelerate cooling.

12.1.2 Granulated Slag

When molten slag is poured into direct contact with large quantities of water, the result is a glassy, granular material with a lower bulk density than air-cooled slag. The jet process uses high-pressure water jets to break up the molten slag stream before it reaches the pit. Jet-granulated slag has a finer size gradation than pit-granulated slag.

12.1.3 Expanded Slag

The ASTM definition of expanded slag is: "the light-weight cellular material obtained by controlled processing of blast furnace slag with water, or with water and other agents such as steam or compressed air, or both." More processes will be encountered in expanded slag plants than in air cooled or granulated slag plants because of the mechanical process variations which are possible.

The amount of water, or less commonly air or steam, used to expand the molten slag is carefully controlled to provide expansion but prevent granulation. The pit is not flooded with water.

12.2 Process Control Operations

12.2.1 Sulfur Gas Emissions

As slag cools from the molten state some sulfur is released. When the slag is dry and atmospheric humidity is low, most of these emissions are in the form of sulfur dioxide. As moisture increases, either in direct contact with the cooling slag or as high ambient humidity, the reactions change and hydrogen sulfide can become the principal form of sulfur gas emissions.

The rate of cooling and the presence of moisture are both factors in the quantity of these emissions. Total emissions will be at their lowest with a long cooling time in the absence of moisture. Accelerated cooling in the presence of moisture maximizes both the total quantity and the concentration of sulfur gas emissions.

On this basis, the granulation process represents the least desirable and air cooling the most desirable slag process from the standpoint of sulfur emissions. This is true with some exceptions. If air cooling is practiced where substantial water spraying is necessary, total emissions could be nearly as great as with granulation.

Even though sulfur gas emissions are a very small percentage of the total sulfur burden of the slag, they can present a localized air pollution problem. Both the American Iron and Steel Institute and the National Slag

Association have researched possible solutions to emission reduction. Results to date are not encouraging. The best recommendations to operators are to extend cooling time and minimize water contact.

12.2.2 Particulate Emissions

The operations of expansion, granulation, pit digging, magnetic iron recovery, crushing, screening, and handling at various transfer points all present potential particulate emissions. Slag forms dust rather than fine fume.

Most plants use water sprays as their primary dust control measure. Baghouses have been used and then abandoned because the dust cakes and blinds the bags. Some wet scrubbers are used, but the highly abrasive nature of slag dust reduces the life of the scrubbers.

Water use in pit digging varies. Hot spots require a lot of water to cool the slag to protect the processing equipment. Water should be sprayed in small streams over a large area rather than deluging a single spot. There is a tradeoff required when digging hot slag. Water minimizes dusting but increases sulfur emissions.

Loading and hauling practices are important in terms of particulate emissions as the height of the drop of material during loading will affect dusting. Front-end loader operators have a great deal of control over this step. Trucks should not be overloaded, preventing spillage on the roadways. Dust from coarse screened material will not blow much in transit, but water spraying of fines or mixed grades of slag is desirable to reduce blowing dust.

12.3 Enforcement Procedure

First, determine whether the slag processing plant is owned and/or operated by the steel producer or a private firm.

For air cooled slag, observe the operating practices. Thin pouring is preferred since it discourages hot spots which must be sprayed heavily on digging, increasing sulfur emissions.

Walk through the crushing, screening, and shipping areas to observe the use of water spray dust control.

Granulation plants produce a large plume as the hot slag is poured into the pit. Particulates and the odors of sulfur dioxide and hydrogen sulfide will be noted in this plume.

Expanded slag plants are similar to granulation plants in that the emissions occur during the expansion step.

Slag processing plants have some control over particulate emissions; air cooled plants have limited operational control over water spraying and pit digging schedules, which are related to sulfur gas emissions; and granulation and expansion plants, by their design, have very little control over their sulfur gas emissions.

Hydrogen sulfide is the major cause of complaints and control is difficult.

The stepwise enforcement procedure, which follows, outlines general observations which can be made at slag plants.

1. Trace the flow of raw materials from the time it arrives at the plant until it leaves.
2. From a distance, observe the raw material and processed materials for dust clouds either from roadways, stock piles, transfer points, crushers, or screening operations. These sources are generally not continuous emitters, but are dependent on the individual activity schedule.
3. Make records of the probable dusty areas for a close-up inspection. These observations should be made from beyond the

plant perimeter on a hillside overlooking the entire complex, if possible, over a period of several hours.

4. Observe the material stock piles when the wind is blowing and note any entrained dust.
5. Observe the methods of moving material at the stockpile.
6. Note dust emissions at the loading stations.
7. If cranes, belts or bulldozers are used to move the materials, note any major dust clouds.
8. Make notes on the lengths and locations of unpaved roadways. Ask what frequency these roadways receive dust preventive treatment such as water, oil, or calcium chloride. Observe the traffic on these roadways, and note whether or not a significant cloud is generated by vehicular movement. Observe the paved, macadamized, and gravel roads for latent dust. Occasionally these roads may become burdened with dust and result in another source of fugitive dust.
9. Observe the transfer points along belt haulage ways. If no dust is noted, no further inspection is required here.

Interpretation of these observations is heavily dependent upon the pertinent regulations governing fugitive dust emissions. Since many of these plants are located on large plots of land, it is important to discriminate between in-plant housekeeping problems and emissions which cross the property line. If fugitive dust violations are apparent, take appropriate action.

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PART II

PRIMARY ALUMINUM INDUSTRY

The annual production of aluminum in the United States, amounting to over 45 percent of the world total, is increasing. In 1972, approximately 5.1 million tons of the metal were produced, an increase of nearly 40 percent since 1968. It has been predicted that by 1984 the production of aluminum will triple. One reason for the increased production is the improving technology that allows for lower prices and better products. In 1854, the metal sold for $100 per pound. By 1898, the price had plummeted to $0.31 per pound, and in 1968, the price was $0.25 per pound. A major reason for aluminum's use is its remarkable physical characteristics. The metal is light, strong, an excellent conductor of heat and electricity, corrosion resistant, highly reflective, has low toxicity, and is easy to cut, mold, extrude, machine, or polish.

In 1972, there were 31 primary aluminum smelters, operated by 13 companies in the United States. Their capacities ranged from 35,000 tons per year to 275,000 tons per year. These plants are listed in Table II-1.

Aluminum is abundant, making up one-twelfth of the earth's crust. Bauxite, a hydrated oxide of aluminum, is the main ore resource for aluminum production. Most of the ore is mined abroad. Jamaica is the largest free-world producer of the crude ore. Other sources are Surinam, France, Guyana, and the United States.

TABLE II-1

U. S. PRIMARY ALUMINUM REDUCTION PLANTS

Location	Company	1972 Capacity (1000 tons/yr)	Cryolite Recovery	Type of Cell	Power
Sheffield, AL	Reynolds	221*	R	HSS	U
Scottsboro, AL	Revere	112	SL	PB	U
Arkadelphia, AR	Reynolds	63*	R	PB, HSS	U
Jones Mill, AR	Reynolds	122*	SH	PB	U-P
Evansville, IN	Alcoa	275	SH	PB	U
Hawesville, KY	National Southwire Aluminum	180	SL	PB	U
Sebree, KY	Anaconda	120**	SL	PB	U
Chalmette, LA	Kaiser	260*	R	HSS	U-P
Lake Charles, LA	Gulf Coast	35	SL	PB	P
Frederick, MD	Eastalco	170	R	PB	U
New Madrid, MO	Noranda	75	SL	PB	U
Columbia Falls, MT	Anaconda	175	SL	VVS, PB	U
Massena, NY	Alcoa	125*	SH	PB	U
Massena, NY	Reynolds	128*	R	HHS	U
Badin, NC	Alcoa	100*	SH	PB	U
Hannibal, OH	Ormet	240	R	PB	U
The Dalles, OR	Harvey	88	SL	VSS	U
Troutdale, OR	Reynolds	140*	R	PB	U

TABLE II-1 (Cont'd)

Location	Company	1972 Capacity (1000 tons/yr	Cryolite Recovery	Type of Cell	Power
Alcoa, TN	Alcoa	200*	SH	PB, VSS	U
New Johnsonville, TN	Conalco	140	SL	PB	U
Corpus Christi, TX	Reynolds	111*	R	HSS	P
Point Comfort, TX	Alcoa	175*	SH	VSS	U-P
Rockdale, TX	Alcoa	275*	SH	PB	U
Ferndale, WA	Intalco	264	SL	PB	U
Goldendale, WA	Harvey	100	SL	VSS	U
Longview, WA	Reynolds	190*	R	HSS	U
Mead, WA	Kaiser	206*	R, SL	PB	U
Tacoma, WA	Kaiser	81*	SL	HSS	U
Vancouver, WA	Alcoa	100*	SH	PB	U
Wenatchee, WA	Alcoa	175*	SH	PB	U
Ravenswood, WV	Kaiser	163*	SL	PB	U

* 1970 Capacity
** 1973 Capacity
R - Recovery Plant on Site
SL - Materials Sold to Other Companies
SH - Materials Treated for Recovery in Parent Company Plant

PB - Prebake
VSS - Vertical Stud Soderberg
HSS - Horizontal Stud Soderberg

U - Utility Furnished
P - In Plant Generation by Gas Fired Unit

In 1967, bauxite usage was 13.1 million tons of imported and 1.8 million tons of native bauxite. Domestic sources are located in Arkansas and Alabama.

Alumina (Al_2O_3) is produced from bauxite by refining, extracting, and calcining the crude ore. The bauxite is dried and then ground in ball mills. A sodium hydroxide solution is added, forming an aluminum hydroxide precipitate which is later calcined to form alumina.

Primary aluminum metal is extracted from the oxide by means of the Hall-Heroult electrolytic process. The alumina is dissolved in a fused bath of sodium aluminum fluoride (cryolite) in carbon-lined pots, which serve as the cathode. Carbon anodes are immersed in the bath to make the electrical contact. The alumina is electrolytically reduced to aluminum and oxygen. Ninety to 240 cells are connected electrically in series to form a potline. Figure II-1 illustrates the operations required to produce aluminum from alumina.

Approximately 7.5 kwh of dc current is consumed per pound of aluminum metal produced. Table II-2 contains this information and other facts concerning materials consumed.

There are two types of reduction cells: prebake and Soderberg. The primary difference in the two pots is the manner in which the anode is prepared. In the prebake cell, the anode is manufactured in the anode plant prior to placing it in the pot. In the Soderberg process, a paste mix of pitch and petroleum coke is poured into a rectangular steel shell which is immersed in the bath and baked by the heat of the pot.

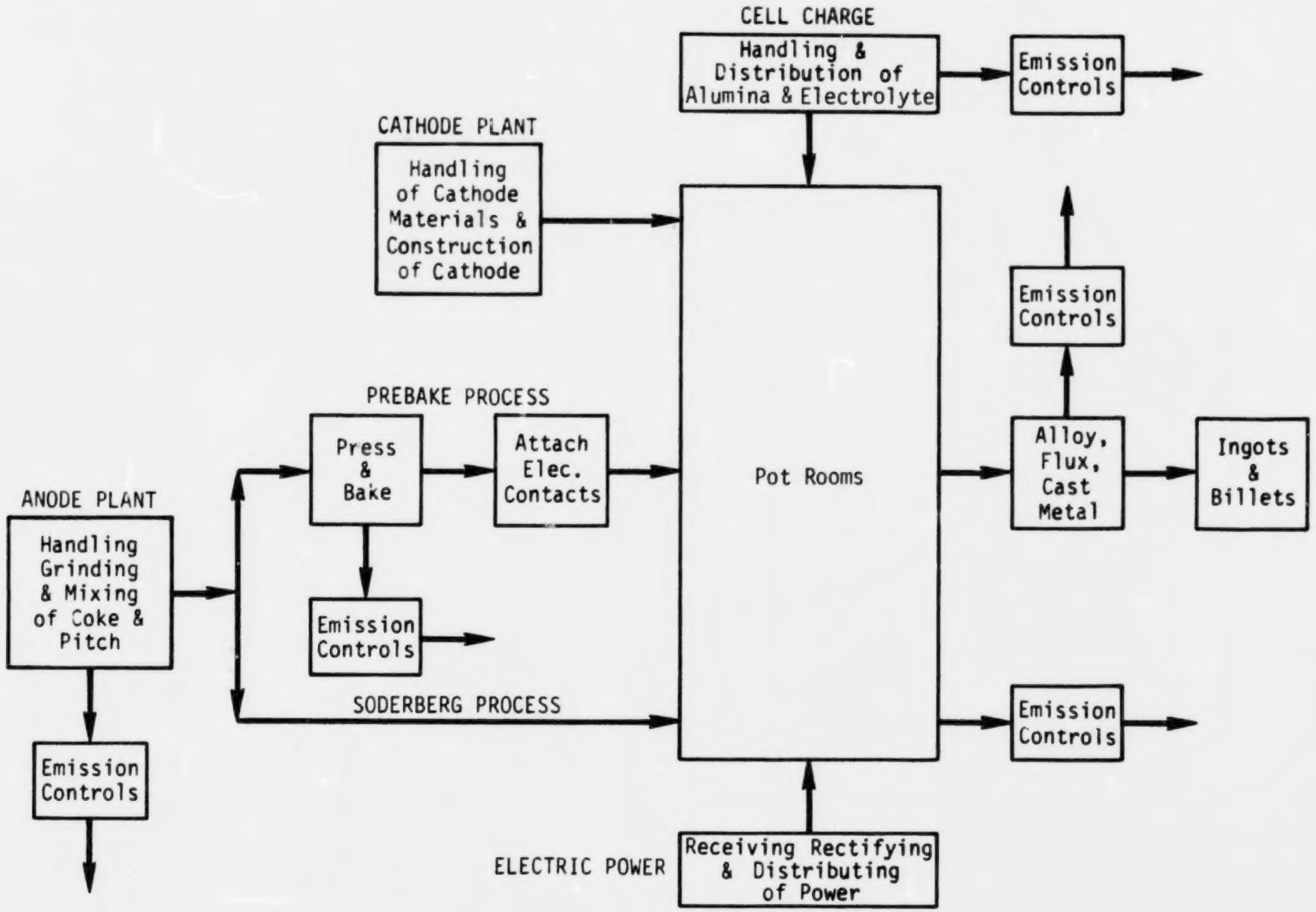

CELL CHARGE
Handling & Distribution of Alumina & Electrolyte
Emission Controls
CATHODE PLANT
Handling of Cathode Materials & Construction of Cathode
Emission Controls
PREBAKE PROCESS
Press & Bake
Attach Elec. Contacts
Pot Rooms
Alloy, Flux, Cast Metal
Ingots & Billets
ANODE PLANT
Handling Grinding & Mixing of Coke & Pitch
Emission Controls
Emission Controls
SODERBERG PROCESS
Emission Controls
ELECTRIC POWER
Receiving Rectifying & Distributing of Power

FIGURE II-1 ALUMINUM REDUCTION PLANT

TABLE II-2

FEED MATERIALS PER TON OF ALUMINUM

Alumina (Al_2O_3)	3860 lb
Cryolite (Na_3AlF_6)	40 lb
Aluminum Fluoride (AlF_3)	70 lb
Fluorspar (CaF_2)	6 lb
Anode Carbon	1000 lb
Cathode Carbon	40 lb
Electric Power	14-16 mwhr

Prebake anodes are replaced approximately every 10 to 20 days. The butts are recycled through the anode plant, which is usually located on the reduction plant site. The petroleum coke is crushed, mixed with ground spent anode butts and combined with pitch to produce the green (uncured) anodes, or, in the case of the Soderberg cell, to form the anode paste. The green anodes are baked and electrical connectors are inserted.

Soderberg anodes are completely consumed during the reduction process. Baking the paste in the cell causes hydrocarbons to be evolved. The hydrocarbons, which are not present in prebake cell effluent, require modification in the air pollution control systems.

Cryolite is absorbed into the carbon cell lining and must be replenished from time to time. The molten bath has a crust on top that must be broken to feed the bath. Fluoride gases and particulates are emitted whenever the pot is charged.

The high cost of cryolite makes recycling economically advantageous. The cell effluents are sometimes scrubbed with caustic to produce cryolite. Fluorides in the cathode are recovered by crushing and grinding the old lining then leaching with caustic at the cryolite recovery plant.

Emissions and sources in the reduction of aluminum include particulates from materials handling and preparation, and particulates and gases from the potlines. The anode plant emits dusts and gases. Particulates are emitted during the anode baking operation. Anode and cathode recovery also generates some particulates and fluorides.

The pollutants of most concern are fluorides. The major source of fluorides is the potline. Controls that have been used include scrubbers, wet and dry electrostatic precipitators, and fluid bed dry filters.

After reduction has occurred, aluminum metal is siphoned from the pots into crucibles for transport to the alloying and holding furnaces. These furnaces are refractory-lined fuel-fired reverberating furnaces.

In these furnaces, various alloying elements are added to produce specific alloys of aluminum. In some cases, alloying elements are added in the pots as well, usually heavy elements such as manganese, copper and iron. When pure aluminum is delivered to the alloying furnaces, these elements will be added as required. Other metals such as magnesium, zinc, nickel and titanium are added in the reverberatory furnace.

Chlorine gas is "blown" through the metal to remove suspended oxides and cryolite. After blowing and before pouring the oxide and cryolite, the surface is skimmed. The aluminum is transferred to the holding furnaces and poured after temperature and alloy constituents are stabilized.

The skims from the alloying and holding furnaces, unless quickly cooled, may ignite. This generates a dense white aluminum oxide particulate. Burned or not, there is a significant quantity of skims which must be handled in some way. Particulate emissions will be generated by spread cooling, dross barrel processing, or any other technique used to handle the skims.

The evaluation of air pollution control systems at primary aluminum smelters is a two-step process. The efficiency of the air pollution control device(s) must be determined, as well as the capture efficiency of the ventilation system.

Emissions from primary aluminum plants are heavily dependent upon the adequacy of routine operating and maintenance procedures.

13. RECEIVING, STORAGE AND HANDLING OF RAW MATERIALS

The possible emissions will be particulates. Fugitive dust regulations will govern.

13.1 Process Description

There are four basic raw materials necessary in the reduction of aluminum which represent potential sources of airborne particulates when handled. These include coke, coal tar pitch, cryolite and alumina. The coke and coal tar pitch usually arrive at the plant in railroad cars with a nugget size of about one-half inch. On the other hand, the alumina and cryolite are fine white particulates which will pass through a 200 mesh screen. Because of its fine size, the alumina material handing system must be fully enclosed to prevent excess loss, especially during high winds. Aluminum reduction plants located inland will usually have the alumina delivered by fully enclosed railroad cars. Those plants which have access to water transportation are likely to have their alumina shipped by completely enclosed barges or freighters. The material handling system used to transfer the alumina from the transportation vessel to the storage silo is always enclosed and usually has a baghouse at the transfer points. Alumina must be moisture free, precluding any use of water sprays to control dust.

Once inside the plant the alumina is transferred by fully enclosed conveyor systems to the pot room. At the pot room, the alumina is loaded into movable storage bins (distributing hoppers) which serve various pot lines. Depending on the plant, these movable storage bins may or may not be fully enclosed. Those bins which have an open top are likely to have dust loss during movement from pot to pot. Particulate losses from this operation can be prevented with the use of canvases or shrouds. When the alumina is charged to the pot, a small dust plume can be observed. Some plants have the hooding and ventilation system designed such that very little dust escapes into the pot room during the charging operation.

The coke and the coal tar pitch are transferred from the storage bins to the prebake anode or paste plant. Because of its physical size it can be handled by front-end high lift loaders. Conveyor systems are not usually covered. Almost all plants will have air pollution abatement equipment connected to the grinding, crushing and screening operations that are required for the production of paste (Chapter 15). Water can be used as a dust suppressant for these raw materials.

These materials are made up of fine particulates which have the potential of causing a hazardous dust explosion. Generally speaking, fugitive dust emanating from aluminum reduction plants is almost thwarted because of the concern over industrial safety. spillage losses and air pollution regulations.

Scrap use is an important aspect of plant economics. All plants recycle a substantial portion of their internally generated scrap. Purchased scrap is another raw material which is handled by the plant.

13.2 Process Control Operation

The high unit cost of the raw materials dictates good control procedures to prevent potential handling losses. The use of enclosed systems for alumina essentially eliminates escape of the raw material. There is a potential for losses of coke dust, but process ventilation is almost universally applied to coke handling systems.

13.3 Enforcement Prodecure

The following enforcement procedure describes general observations to be made at primary aluminum plants.

1. Trace the flow of raw materials from the time they arrive at the plant until they enter the pots.
2. From a distance observe the raw material and processed materials for dust clouds either from roadways, stock piles, transfer points, crushing and screening operations, dross handling, plant construction activities, etc. These sources are generally not continuous emitters, but depend on the individual activity schedule.
3. Make records of the dusty areas for a close-up inspection. These observations should be made from beyond the plant perimeter on a hillside overlooking the entire complex, if possible for a period of several hours.

4. Observe the raw material stock piles when the wind is blowing and note any entrained dust.
5. Observe the material moving methods at the stockpiles.
6. Note any dust emissions at the bulk unloading stations.
7. If cranes, belts or bulldozers are used to move the raw materials, note any major dust clouds.
8. Make notes on the lengths and locations of unpaved roadways. Ask if and at what frequency these roadways receive dust preventive treatment such as the application of water, oil or calcium chloride. Observe the traffic on these roadways, and note whether or not a significant dust cloud is generated by vehicular movement. Observe the paved, macadamized and gravel roads for latent dust. Occasionally these roads may become burdened with dust and result in another source for fugitive dust.
9. Observe the transfer points along belt haulage ways. If no dust is noted, no further inspection is required here.

The Inspector's Worksheet which follows may be useful for record keeping. Interpretation of these observations is dependent upon the pertinent regulations governing fugitive dust emissions. Since many of these plants are located on large plots of land, it is important to discriminate between in-plant housekeeping problems and emissions which cross the property line.

If fugitive dust violations are apparent, take appropriate action.

INSPECTORS WORKSHEET

FOR RECEIVING, STORING AND HANDLING OF RAW MATERIALS

Plant Id.____________________________________

Date of this Inspection______________ Date of last Inspection______________

Type of Plant____________________________________

Capacity of Plant________________________________

Source Location	Type Material	Wind Direction Wind Speed (mph)	Plume Description	Preventive Measures
Sample Alumina elevator	alumina	SW/10	slightly visible-white	baghouse used
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				

14. PREPARATION OF ALUMINA

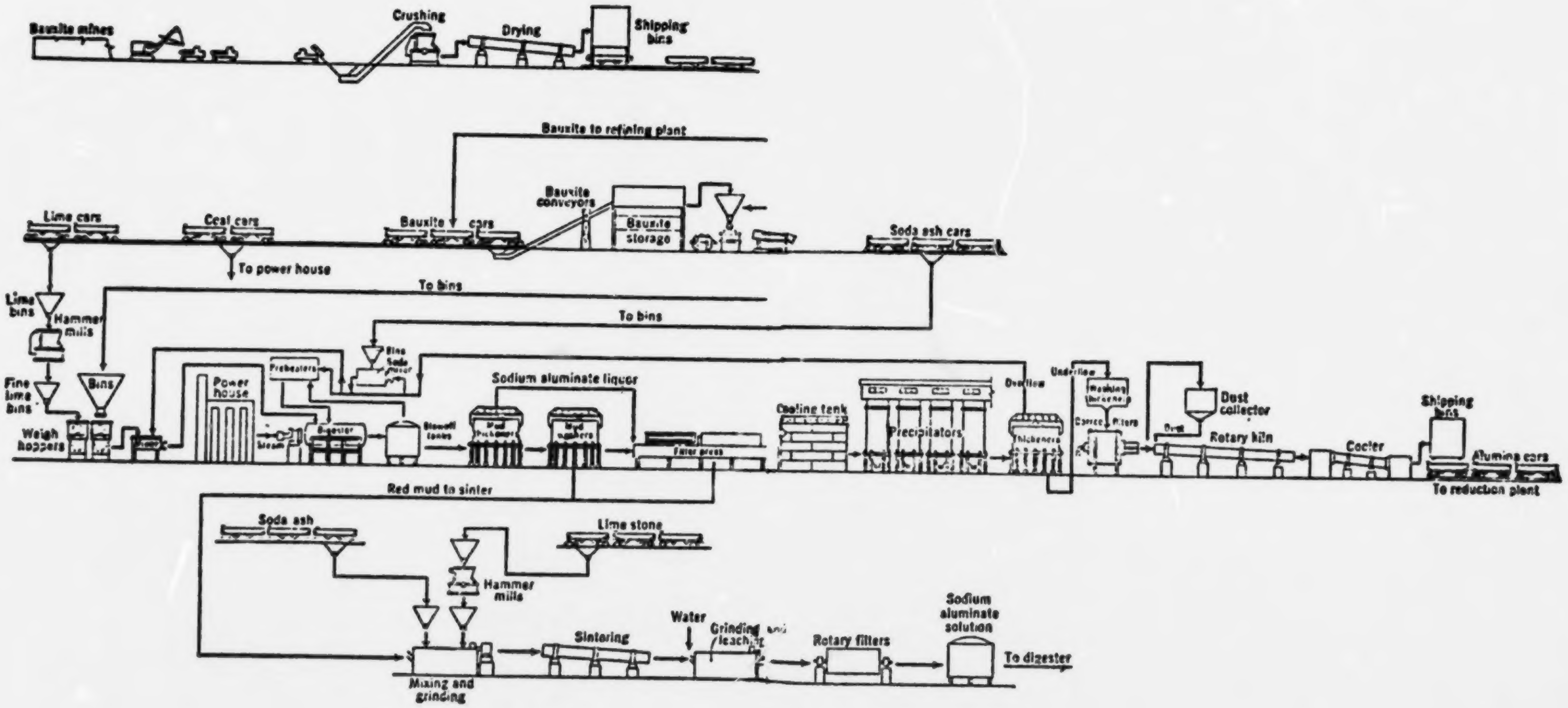
The possible emissions will be particulate. Likelihood of emissions is remote.

14.1 Process Description

The principal ore used in the production of aluminum is bauxite, and although large deposits of the ore are found in Alabama, Georgia, Mississippi, Tennessee, Virginia and Arkansas, much of the better grade ore is imported. A preliminary process of converting bauxite into pure alumina, which is used in the reduction process, is necessary for the production of high quality aluminum.

Most of the world's aluminum is reduced from alumina, which is produced from bauxite by the Bayer process. Generally, there are two types of domestic bauxite; hard or rock bauxite and soft or clay-like bauxite. In addition to the aluminum oxide, bauxite ore will contain roughly 10 to 30 percent of iron oxide, 4 to 18 percent silica and 2 to 5 percent titania. Figure 14.1 shows the process involved in the preparation of alumina from bauxite. After being mined in open pits, the ore is first dried and ground to pass through a 100 mesh screen. Soda ash and lime are mixed with bauxite in proper proportion and treated in digesters at elevated temperature and pressure. Because of the chemical properties of the various impurities found in the bauxite, most of the alumina goes into solution as sodium aluminate during the reaction. Iron oxide and titanium oxide are virtually unaffected.

When this digestion is completed the sodium aluminate liquor is separated from the suspended "red mud" by settling and filtration. Red mud carried over with the liquor is an impurity and must be removed, otherwise the iron oxide will cause difficulty and contamination in the electrolytic reduction process.



Bauxite mines
Crushing
Drying
Shipping bins
Bauxite to refining plant
Bauxite conveyors
Lime cars
Coal cars
Bauxite cars
Bauxite storage
Soda ash cars
To power house
To bins
To bins
Lime bins
Hammer mills
Fine lime bins
Bins
Weigh hoppers
Power house
Preheaters
Bins
Soda
Steam
Digester
Blowoff tanks
Mud thickeners
Mud washers
Sodium aluminate liquor
Filter press
Cooling tank
Precipitators
Overflow
Thickeners
Underflow
Washing thickeners
Filters
Dust collector
Rotary kiln
Cooler
Shipping bins
Alumina cars
To reduction plant
Red mud to sinter
Soda ash
Lime stone
Hammer mills
Mixing and grinding
Sintering
Water
Grinding and leaching
Rotary filters
Sodium aluminate solution
To digester

FIGURE 14.1 THE ALCOA COMBINATION PROCESS

The sodium aluminate liquor is pumped to tanks where it is "seeded" with a small amount of aluminum hydroxide. The liquor is slowly cooled over a period of about 30 hours. Aluminum hydroxide precipitates from the sodium aluminate liquor. The aluminum hydroxide precipitate is washed to remove any soda and then calcined in rotary kilns at a temperature of about 1,000°C. The resultant alumina is cooled. It contains at least 99.6 percent aluminum oxide.

The alumina is sent to the reduction plants in enclosed bulk transporters as a minus 200 mesh white powder.

Scrubbers, or baghouses, controlling effluents at the aluminum hydroxide kiln can be expected to be high efficiency control devices.

The mining, drying and grinding of bauxite is generally conducted at the mine. Processing from bauxite to alumina is a separate operation which may be carried out at a separate plant site or at a reduction plant.

14.2 Process Control Operation

The operational variable which would affect air pollution emissions from the calcining of aluminum hydroxide is the adequacy of the control equipment.

The major source of emissions will be from the kiln, and from the material handling of the ore and alumina. Scrubbers are commonly used to control the effluents from the aluminum hydroxide calcining kilns. Scrubbers are similar to those used in the cryolite recovery plants. The slurry that is generated is recycled directly into the process. Another factor which affects air pollution emissions is the condition of the collection hood at the discharge end of the kiln. A factor which would affect the amount of air pollution emissions emanating from the kiln is the process feed rate.

Natural gas is the principal fuel used to calcine the alumina in the kilns. The major pollutant associated with the calcining of aluminum hydroxide is particulate matter, in the form of fine white Al_2O_3.

14.3 Enforcement Procedure

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plumes. If in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine point(s) of origin and require corrective action.

15. ANODE MANUFACTURING

This is a major potential particulate and minor sulfur dioxide, hydrocarbon and fluoride emission source. Particulate emissions are mainly a function of the adequacy of the control system.

15.1 Process Description

Anodes for prebake pots weigh approximately 500 pounds and are consumed in less than a month. In Soderberg pots an equivalent amount of paste must be supplied. Substantial tonnages of anode material must be processed at aluminum smelters.

Carbon paste preparation consists of crushing, grinding, screening and classifying, combining of carefully sized fractions with a pitch binder, and mixing. The preparation plant is termed the "green mill" by the industry and may produce anode paste for Soderberg cells, cathode paste, or green pressed anodes for prebake treatment. Figure 15.1 shows a typical flowsheet for a Soderberg paste plant and Figure 15.2 shows a typical

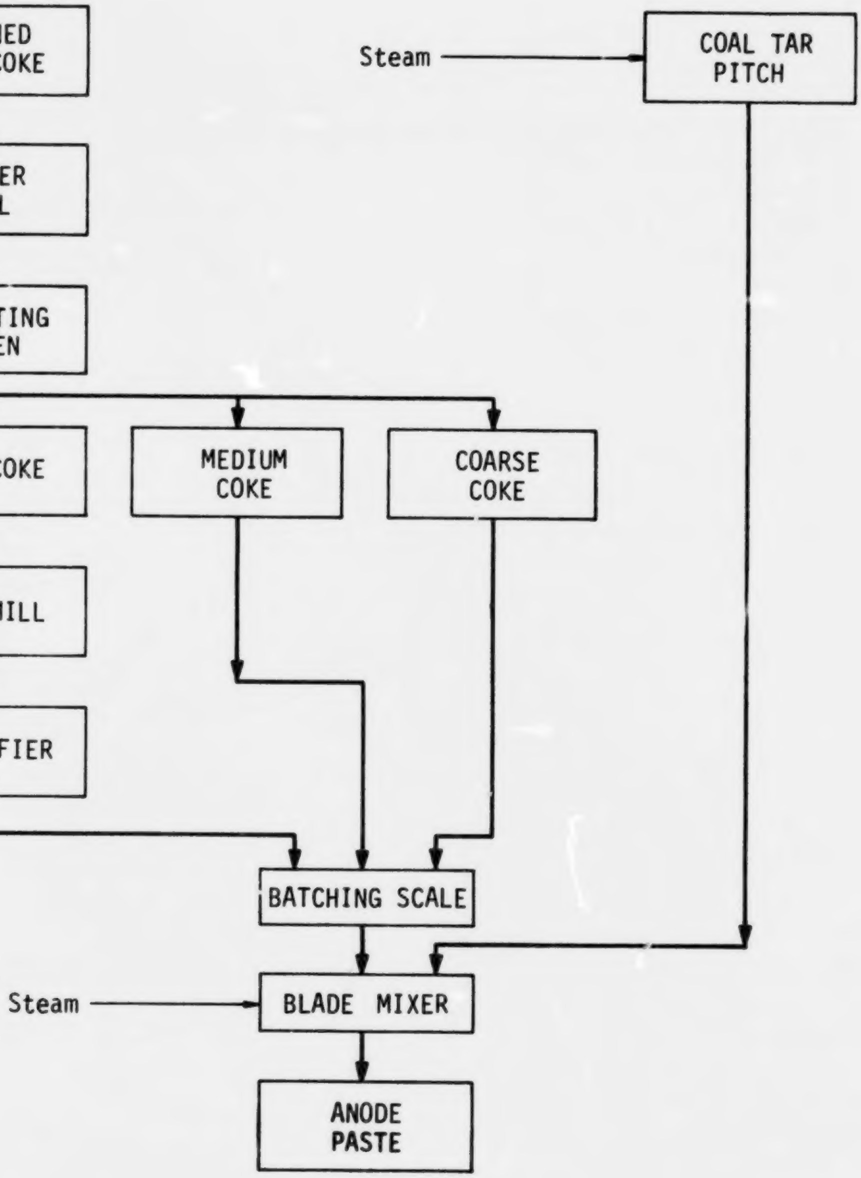

CALCINED PET. COKE
Steam
COAL TAR PITCH
HAMMER MILL
VIBRATING SCREEN
FINE COKE
MEDIUM COKE
COARSE COKE
BALL MILL
CLASSIFIER
BATCHING SCALE
Steam
BLADE MIXER
ANODE PASTE

FIGURE 15.1 SODERBERG ANODE PASTE PRODUCTION PROCESS

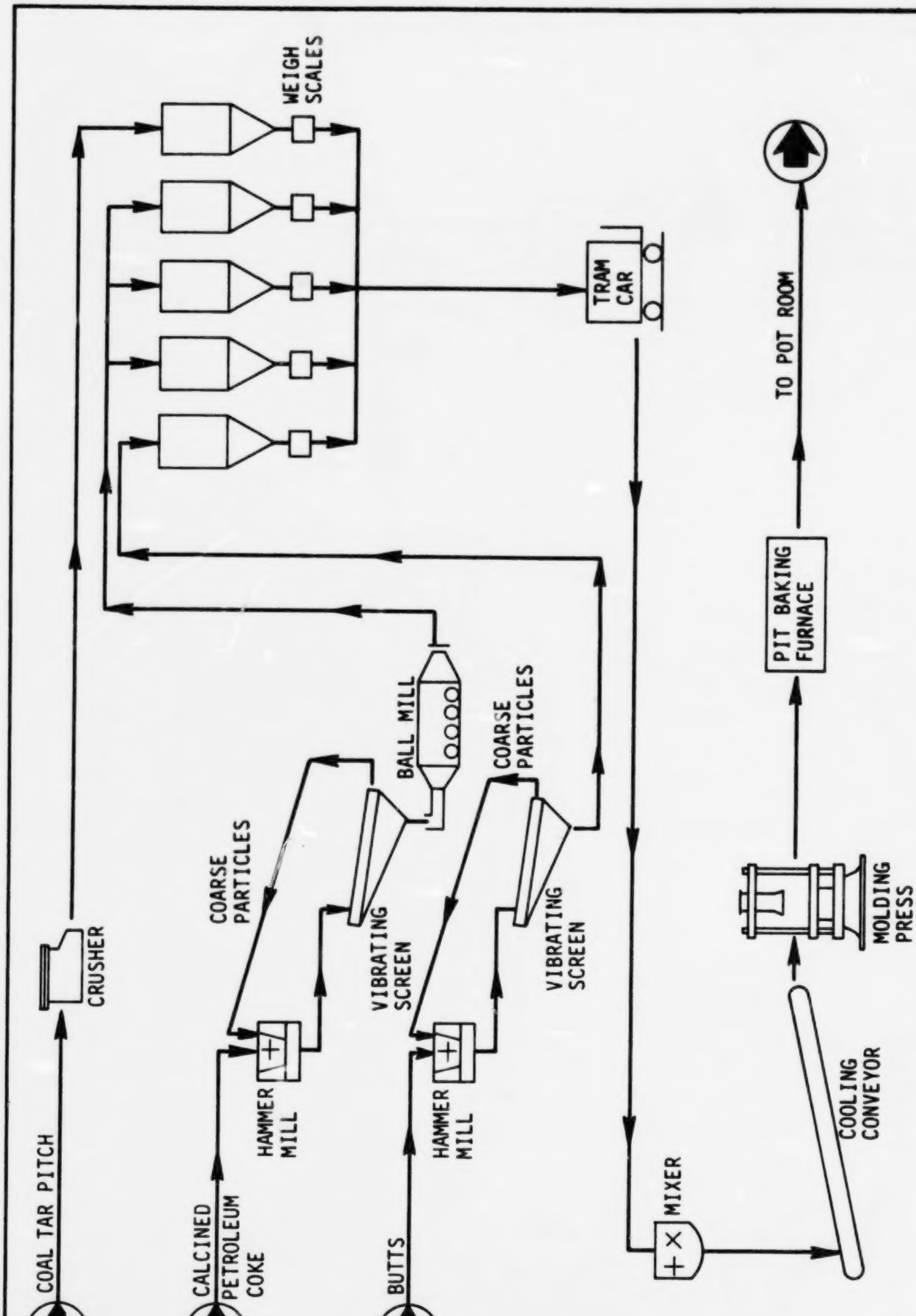

COAL TAR PITCH
CRUSHER
CALCINED PETROLEUM COKE
HAMMER MILL
COARSE PARTICLES
VIBRATING SCREEN
BALL MILL
BUTTS
HAMMER MILL
VIBRATING SCREEN
COARSE PARTICLES
WEIGH SCALES
TRAM CAR
MIXER
COOLING CONVEYOR
MOLDING PRESS
PIT BAKING FURNACE
TO POT ROOM

FIGURE 15.2 PREBAKE ANODE FLOWSHEET

flowsheet for the paste preparation and green anode pressing of prebake anodes. Forming of the green anodes is accomplished either by hydraulic molding or vibratory jolting of the stiff anode paste into dimensionally stable blocks ready for baking and rodding.

Solid raw materials (calcined petroleum coke, anthracite coal, solid pitch, and green petroleum coke, as required for various kinds of paste mixes) are received in bulk and conveyed to carbon plant storage. Wetting agent sprays are used in some green mills to reduce dusting conditions inherent in materials handling.

Material is reclaimed from storage, usually by front-end loaders with enclosed cabs, and fed to combinations of crushing equipment in closed circuit with vibrating screens followed by grinding units. Sized fractions of crushed and ground material are separated and stored in mix bins for make-up of paste composition.

Cleaned reclaimed spent anodes and anode scrap from prebake plant operations are similarly crushed and sized for recycle to prebake anode preparation.

Dry solids are drawn from the mix bins in weighed proportions to provide batches of carefully controlled size distribution and composition, which are then transferred to steam-jacketed hot mixers. For baked anode pastes the mixer feed contains either solid crushed coal tar pitch which is softened and blended in the mixers or hot liquid pitch to provide the paste binder. For Soderberg paste, a liquid pitch is used, metered to the mixers.

The hot Soderberg paste is either discharged directly from the batch mixers to transfer cars which convey it to the cell rooms for anode replenishment, or it may be cooled and briquetted.

The prebake paste, less fluid than the Soderberg material, is transferred from the mixers to anode molds, in which the self-supporting green anode is formed by compaction.

Green anodes are delivered to the baking plant. Ring furnaces, Figure 15.3, are sunken baking pits with surrounding interconnecting flues.

Anodes are packed into the pits, with a mixture of green coke and calcined petroleum coke filling the space between the anode blocks and the walls of the pits. A 10 to 12 inch blanket of calcined petroleum coke fills the top of each pit above the top layer of anodes.

The pits are heated with natural gas or oil-fired manifold burners for a period of about 40 hours. The flue system of the furnace is arranged so that hot gas from the pits being fired is drawn through the next section of pits to gradually preheat the next batch of anodes before they are fired, in turn, when the manifold is progressively moved. The cycle of placing green anodes, preheating, firing, cooling, and removal is approximately 28 days.

The ring type furnaces use outside flues under draft. The flue walls are of dry-type construction. Volatile materials released from the anodes during the baking cycle pass through the walls and mix with the flue gases.

Air contaminants from the ovens include tarry hydrocarbons, particulates, sulfur dioxide, and fluorides. Some prebake oven installations use scrubbers to control emissions.

Another source of particulate emissions at the ring furnace occurs when coke or anthracite is placed over each ditch. This layer acts as a

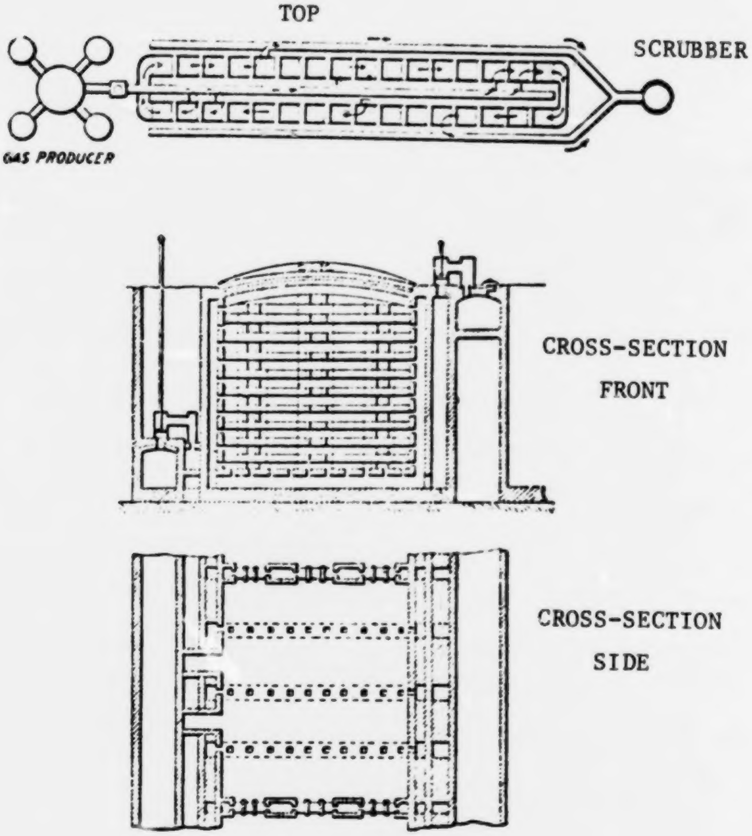

TOP
SCRUBBER
GAS PRODUCER
CROSS-SECTION
FRONT
CROSS-SECTION
SIDE

FIGURE 15.3 OVEN RING FURNACE OR BAKING POT

seal and insulator for keeping heat in the pit. The coke is a fine granulated material less than a 1/4-inch in diameter. When the coke bed is removed, after the anodes have been baked, fine particulates can become airborne.

A second type of furnace, the tunnel kiln, has been developed for baking anodes. The kiln is an indirect fired chamber in which a controlled atmosphere is maintained to prevent oxidation of the carbon anodes. Green anode blocks are loaded on transporter units which enter the kiln through an air lock, pass successively through a preheating zone, a firing zone, and a cooling zone, and leave the kiln through a second air lock. The refractory beds of the cars are sealed mechanically to the kiln walls to form the muffle chamber, while permitting movement of the units through the kiln.

The muffle chamber is externally heated by combustion gases, and the products of combustion are discharged through an independent stack system.

Effluent gases from the kiln may be introduced into the fire box to recover the fuel value of hydrocarbons and reduce the quantity of unburned hydrocarbon to approximately 1 percent of that coming from a ring furnace. Further reduction of solid and gaseous effluent may be achieved by the use of scrubbers or electrostatic precipitators.

While the tunnel kiln presents mechanical problems in design and operation, it is reported to have several appreciable advantages over the ring-type of furnace. Baking cycle from green to finished anode is much shorter. Anode baking is more uniform. Space requirements for equal capacity furnaces are less. Smaller gas volumes are handled through the furnace emission control system.

Baked anodes are delivered to air blast cleaning machines utilizing fine coke as blasting grit. Fins, scarfs, and adherent packing are removed by this treatment. The baked anodes are then transferred to the rodding room.

Steel bars or pins are inserted in the anodes to provide the electrical connection between the bus and the carbon block.

15.2 Process Control Operation

There are several operating variables which will affect air pollution emissions from the anode plant:

1. Adequacy of the crushing, grinding and screening hoods,
2. Fluoride, content of anode butts,
3. Sulfur content of petroleum coke,
4. Temperature of the ovens,
5. Method used for covering and uncovering anodes in ring furnaces,
6. Efficiency of air pollution control equipment.

Air pollution control devices are usually installed on many of the material handling, crushing, screening, and mixing operations to capture valuable raw materials. Since the coal tar pitch may be a fine fluffy material it is easily entrained by air. In almost all plants, it will be transported by a fully enclosed pneumatic conveying system. Nearly every anode plant will have a control booth to monitor the transport system, the crushing and screening system, the mixing, and precision weighing operations. The indicators on the control booth may only be lights which indicate that chutes are open, that conveyors are in motion, or that pressure is being applied to a press.

The control booth may also include monitors of the control systems. The controls may indicate flow rates, temperatures, and fan amperage. Particulates captured by dry collectors are usually sent directly into the bins for reprocessing. On the other hand, slurry from butt grinding control scrubber is dried before returning to the butts bin.

Plants which use no control systems or have only selected operations with abatement devices will usually have soot on the floor or suspended in the air of the anode building. Some soot can be expected in the best controlled plants.

Fluoride gases are a major concern in emissions from the oven baking process. Other emissions from the oven baking process include hydrocarbons and sulfur dioxide. The hydrocarbons come from the coal tar pitch following the breakdown from tar products.

Another operation procedure which affects particulate emissions is the method used to cover and uncover the anodes in the ring furnace. Some plants use no control system for handling the coke and as a result dust is apparent in the room. For those plants which do control coke dust, operators will have a small baghouse attached to the crane which charges the coke to the furnace pits. The baghouse acts as a "vacuum cleaner" in controlling particulates from becoming airborne.

15.3 Enforcement Procedure

The objective of anode plant operation inspection is to establish compliance with gaseous and particulate emission regulations. In order to accomplish these objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,

3. Current controlled and uncontrolled particulate and gaseous emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. This data should be obtained from the company representative prior to plant inspection. Production levels, feed weight rates, and emission control equipment operating conditions may be monitored by the plant operator and may be recorded in the operator's daily log or displayed on instrument panels.

The pollutant of most concern in the paste shop is particulate matter. An immediate tip-off regarding the adequacy of air pollution abatement systems would be the soot lying on the floor and hanging on the walls. Those plants which have good air pollution capture systems will usually be fairly clean and have no build up of the black fluffy material. The grinding, crushing, screening and mixing operations should be examined thoroughly for capture efficiency at the hoods and equipment openings.

Anode paste shops may not operate continuously. It is possible that the paste shop will not be in operation during a routine periodic inspection.

The enforcement official should check past records to determine whether or not the air pollution abatement equipment has been operating satisfactorily.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plume. If in excess of allowable limits, appropriate action should be taken.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine point(s) of origin and require corrective action.

Baking furnaces will always operate three shifts per day continuously, even on the weekends. As background data it is important to establish the anode baking rate and cycle, the number of furnaces in operation, and the maximum temperature of the furnace. When the temperature is increased, curing time is reduced and air pollution emissions increase. The enforcement official should check the operating circumstances during his visit with design and typical operating characteristics as obtained prior to his visit.

Certain observations need to be made at the furnaces. If the enforcement official notices strong odors of sulfur dioxide or hydrocarbon, it may be an indication that the ventilation system is not adequate, may have severe leaks, or may be plugged.

The enforcement official should observe the method of charging anodes to the oven and removing anodes from the ovens. The granulated coke or anthracite used to cover anodes can become a fugitive dust problem. Some plants have pneumatic systems which act as a vacuum cleaner to minimize dust during the charging and removing operation. The amount of natural gas fired in the ring furnaces is not important.

Because of the fluoride emissions from the ovens, low energy scrubbers may be used. The enforcement official should note the operating parameters of the scrubber and check past records of its performance.

The enforcement official should complete the Inspector's Worksheet for prebake anode plants and perhaps make some quick checks for particulates,

INSPECTORS WORKSHEET

FOR PREBAKE ANODE PLANTS

GENERAL

Plant Id.____

Date of this Inspection____________________ Date of last Inspection__________

OPERATING VARIABLES

Paste Shop

Raw material feed rate: coal tar pitch_______lb/day, calcined petroleum coke________lb/day, butts____________lb/day.

Percent Sulfur in Coke______%

No. of Anodes Produced per Shift________

No. of Shifts Anode Plant Operates_______

Furnaces: Ring ☐ Tunnel ☐ ________ ☐

No. of Anodes Baked per Day_________

No. of Furnaces________, operating this inspection_________

Maximum Temperature of Furnace__________ °F

Baking Time_______hours

AIR POLLUTION ABATEMENT EQUIPMENT

Devices used at Paste Shop__________________________________

Devices used at Furnaces___________________________________

Parameters	Paste Shop	Furnaces
Pressure drop, in. H_2O		
Scrubber water flow rate, gpm		
Exhaust Flow Rate, scfm		
Exhaust Gas Temperature, °F		

AIR POLLUTION TESTS

Paste Shop - Particulates________lb/hr

Furnace - Particulates____________lb/hr, SO_2__________ppm, HF__________ppm, HC__________ppm

Tested by_______________________________ Dated______________________________

VISUAL OBSERVATIONS

Mixing Hoppers____

Presses____

Appearance of Building Interior______________________________

____

Odors____

Charging Coke to Furnace____________________________________

____

Extracting Anodes from Furnace_______________________________

____

Time In__________ Time Out__________

fluoride, and sulfur dioxide emissions. These procedures are described in Part VII of this manual.

16. REDUCTION OPERATIONS

This is a major potential fluoride and particulate emissions process. Sulfur dioxide is a minor emission. Emissions are mainly a function of ventilation and collector design and maintenance. Operating practices and routine maintenance can have a major effect on emissions.

16.1 Process Description

The Hall-Heroult process is the electrolytic reduction of alumina to aluminum in a fused cryolite electrolyte. A carbon-lined steel vessel serves as both the cell body and cathode. The cell anodes are carbon blocks, suspended above the cell body and immersed in the electrolyte.

In operation, electric current passes through the fused cryolite electrolyte. Alumina in solution is reduced at the cathode to metallic aluminum. The aluminum, which is liquid at cell temperatures, collects on the bottom of the cell since it is more dense than the electrolyte. At the anodes, carbon is consumed by oxidation. The cell reaction is:

$$2\ Al_2O_3 + 3C \longrightarrow 4\ Al + 3CO_2$$

This reaction theoretically requires approximately 2.5 kwh of energy per pound of aluminum produced. Due to heat loss through the pot, sensible heats of reaction and unwanted electrode reactions, 6 to 9 kwh per pound of aluminum are consumed.

The reduction cell, or pot, is a reinforced steel container, insulated to retain heat. The pot contains an inner carbon lining which forms the cathode of the cell. The lining varies from 6 to 18 inches in thickness and consists of either a rammed mixture of pitch and coke or prepaked cathode blocks laid in place with pitch sealing. The resulting cathode box measures about 12 to 20 inches deep, 30 feet long and 10 feet wide. Steel cathode current collectors are embedded in the lining and connect to a cathode buss. Between 90 and 240 cells are connected in series forming a pot line. Each pot line requires 4 to 6 volts per pot and 50,000 to 200,000 amperes.

During the reduction process, the anodes are steadily consumed thus liberating oxygen from the alumina. Ten to twenty days is a typical life for an anode. Cathodes, on the other hand, usually last two to four years before relining is necessary.

The cell bath is approximately 85 percent cryolite (Na_3AlF_6), 8 to 10 percent fluorspar (CaF_2), and 2 to 6 percent alumina (Al_2O_3). A crust consisting of alumina and frozen cryolite forms over the bath preventing air oxidation of the anode and helping retain heat in the 1,750°F bath. Two tons of alumina are required for each ton of aluminum produced. Every five or six hours the crust is broken and fresh alumina is added.

Periodically, usually daily, the aluminum collected on the cell bottom is siphoned off. A thermally insulated steel crucible with a vacuum line siphons the molten metal. Usually three or four cells are tapped into a crucible. The metal is transferred to the cast house where it is used.

Aluminum pots must be run within closely controlled operational parameters. Emissions can increase sharply when a pot is "sick". The two main causes of a "sick" pot are poor current distribution and abnormal bath temperatures. In one case, when alumina concentration of the bath is depleted, a buildup of CF_4 gas forms on the anode. Voltage and bath temperature rise, the latter causing the elevated emissions. The pot must then be stirred and alumina added to return the pot to normal operation. Causes of "sick" pots include:

1. Voltage too low,
2. Bath and metal violently agitated while putting out an anode effect or preparing pot for tap,
3. Muck formations due to either too much ore or too low bath temperature,
4. Unlevel anode due to faulty jack system,
5. Grounds such as anode spikes and long ends on anodes,
6. Too much metal,
7. Faulty voltmeter,
8. Too little metal.

The engineering design and maintenance of ventilation systems is the most critical factor in air pollution control at a primary aluminum plant. Although the capture systems for prebake, vertical stud Solderberg (VSS) and horizontal stud Soderberg (HSS) are different, there are several factors which apply throughout.

Pots cannot be completely hooded (shielded) at all times because several operations must be routinely conducted within the confines of the hood. The crust on the pot must be broken every few hours to add alumina. "Sick" pots must be stirred. Anodes must be replaced (prebake) or studs must be moved (Soderberg). Other operations such as gas-hole punching also require access to the pot. The important point is that the shields must be opened at frequent intervals.

Some of the factors leading to the deterioration of the efficiency of capture ventilation are:

1. Anode blocks handled from cranes often swing into shields used as hoods on prebake cells, denting and deforming them.
2. "Sick" cells may get so hot that some or all shields actually melt down; some shields partially damaged this way may improperly be kept in service.
3. Shields removed for anode replacement, bath sampling, and other routine work may be replaced haphazardly, leaving gaps between some shields.
4. Ducts should be balanced for uniform collection from all cells, and damper positions should be marked; if dampers are closed when a cell is removed, or opened to provide better collection under non-normal operation, the damper should be carefully reset.
5. When reduction cells age, the cell lining (cathode) absorbs bath and deforms the steel shell so that it "bows out", perhaps as much as a foot on each side. This impairs the gas seal, especially on HSS cells.
6. HSS cells evolve tars in considerable quantity, and these condense and deposit in ductwork, sometimes plugging it completely. Regular cleaning of the ductwork, especially of small ducts near the cells, is a requirement.
7. General housekeeping is extremely important - a pot room can be a clean and attractive place to work - but if housekeeping is poor, doors and shields will be left open unnecessarily, damaged doors and shields will appear part of the "normal" appearance, and capture effectiveness will deteriorate more than in direct proportion.

Procedures for controlling some of these conditions have been developed. In a prebake plant, inspectors tour each pot line, noting for each cell the "equivalent shields" misplaced, damaged, or missing, recording observations to the "nearest 1/8 shield." The number of equivalent shields is totalled for each pot line and becomes a performance criterion. Observer error is large, but differences between pot lines may be larger, and the system has proven effective. Objective criteria may be developed, especially as improved measurement techniques are evolved.

16.1.1 Prebake Pot Operations

Anodes which have been pre-formed and baked are used in these pots. The prebake cell, Figure 16.1, uses up to 24 anode assemblies. These are clamped to the anode buss, which has a vertical travel of 10 to 14 inches. As the anode is consumed it is moved down to maintain proper position in the pot. New anodes are installed using an overhead crane.

The air pollutants generated by prebake pots consist of fairly coarse alumina dust, condensed metallic fumes, sulfur dioxide, fluorides in both gaseous and particulate form. There are virtually no hydrocarbons, these having been baked out at the anode furnaces.

Most of the particulate emissions originate during the charging of fresh alumina and other materials to the cell. This is a result of the breaking of the cell crust (usually with a jack hammer) and subsequent agitation of the bath. Some carbon particles are emitted during anode replacement operations. Other particulates include aluminum fluoride (AlF_3), cryolite (Na_3AlF_6), fluorspar (CaF_2), iron oxide (Fe_2O_3), and chiolite ($Na_3Al_3F_4$).

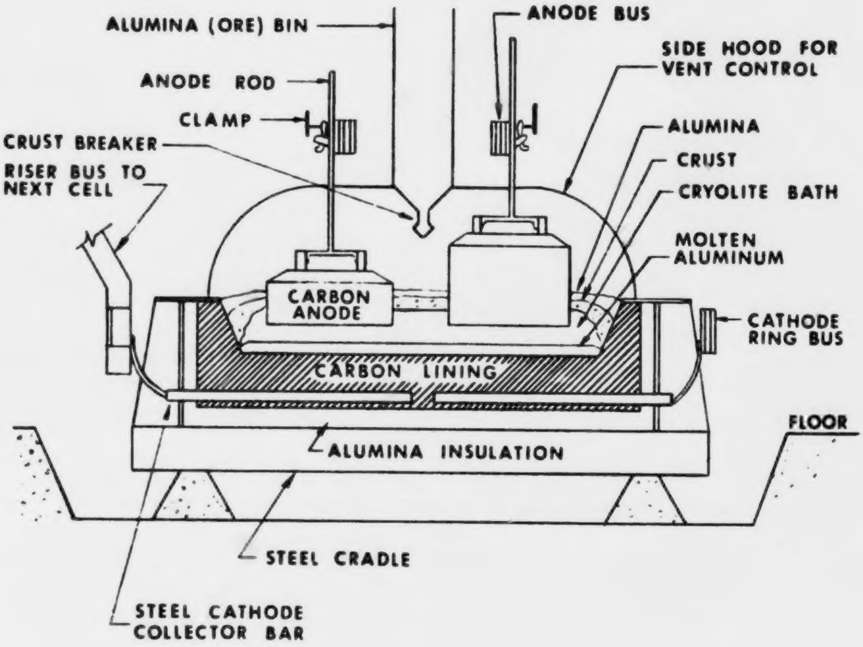

ALUMINA (ORE) BIN
ANODE BUS
SIDE HOOD FOR VENT CONTROL
ANODE ROD
CLAMP
ALUMINA
CRUST BREAKER
CRUST
RISER BUS TO NEXT CELL
CRYOLITE BATH
MOLTEN ALUMINUM
CARBON ANODE
CATHODE RING BUS
CARBON LINING
FLOOR
ALUMINA INSULATION
STEEL CRADLE
STEEL CATHODE COLLECTOR BAR

FIGURE 16.1 PREBAKE REDUCTION CELL

The high fluoride electrolytic bath is the source of the emitted fluorine compounds. Hydrogen fluoride gas is caused by the hydrolysis of vaporized fluoride salts. This is the most harmful of the pollutants emitted due to its high toxicity and extreme corrosiveness.

The consumption of the carbon anodes liberates significant quantities of sulfur dioxide (SO_2). The source of the sulfur is the petroleum coke used in the manufacturing of the anodes. The average sulfur content in the coke used today is 3 percent. Sulfur dioxide effluent for 1,000 pounds of aluminum produced ranges from 15 to 50 pounds, depending upon the exact sulfur content of the coke.

A typical analysis of the emissions from a single prebake cell are shown in Table 16.1.

Table 16.1 PREBAKE REDUCTION CELL EFFLUENTS

(Quantity - lb/1,000 lb Al)

Component	European	U.S.
CO_2	1,500	----
CO	250	----
SO_2	6.5	30(1)
F (gaseous fluorides)	10.3	13.1
F (solid fluorides)	6.3	8.8
Total Fluorides (F)	16.6	22.5
Total Solids	25 to 63	45.6

(1)Estimate based on 3 percent sulfur in anode cokes.

16.1.2 Vertical Stud Soderberg Pot Operations

The Soderberg pot operation uses a coke and pitch paste to form the cell anodes during cell operation. The paste is fed into a steel casing and baked in place by the heat of the electrolytic bath eliminating the necessity of anode forming and baking operations.

The materials used, pot specifications, and tapping methods of the Soderberg cells are identical to those of the prebake operations. The difference between them is solely in the type of anode used, types of air pollution emissions (hydrocarbons are present in Soderberg cells), and control systems.

There are two kinds of Soderberg cells: the "horizontal stud" or "side pin" (HSS) and the "vertical stud" (VSS). Figure 16.2 shows the typical layout of the vertical stud pot. The "vertical" notation refers to the electrical connection by means of steel studs to the anodes as the vertical studs enter the anode mass from the top. The "green anode paste" is poured into the top of an open end steel casing and baked by cell heat. In effect, there is a continuous anode without the need for replacement as in the prebake operation. As a stud tip comes close to the cell bath it is repositioned upward.

16.1.3 Horizontal Stud Soderberg Pot Operations

The Soderberg pot operation uses a coke and pitch paste to form the cell anodes during cell operation. The paste is fed into a steel casing and baked in place by the heat of the electrolytic bath eliminating the necessity of anode forming and baking operations.

The materials used, pot specifications, and tapping methods of the Soderberg cells are identical to those of the prebake operation. The

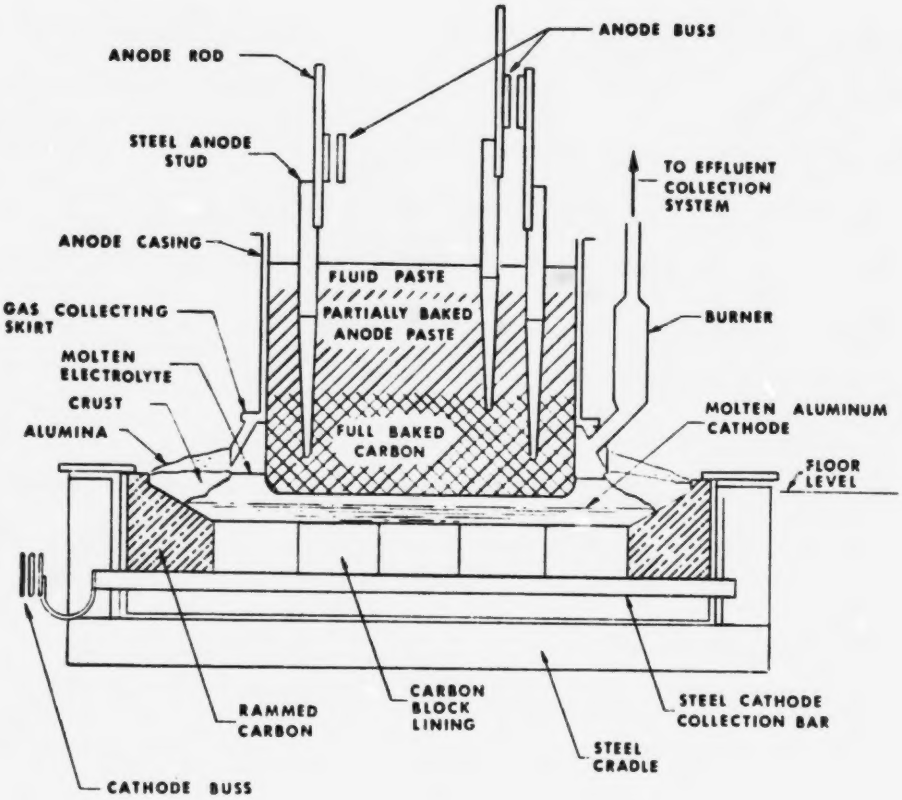

ANODE ROD
ANODE BUSS
STEEL ANODE STUD
TO EFFLUENT COLLECTION SYSTEM
ANODE CASING
FLUID PASTE
PARTIALLY BAKED ANODE PASTE
GAS COLLECTING SKIRT
BURNER
MOLTEN ELECTROLYTE
CRUST
ALUMINA
FULL BAKED CARBON
MOLTEN ALUMINUM CATHODE
FLOOR LEVEL
RAMMED CARBON
CARBON BLOCK LINING
STEEL CATHODE COLLECTION BAR
STEEL CRADLE
CATHODE BUSS

FIGURE 16.2 VSS SODERBERG CELL

difference between them is solely in the type of anode used, types of air pollution emissions (hydrocarbons are present in Soderberg cells), and control systems.

There are two kins of Soderberg cells; the "horizontal stud" or "side pin" (HSS) and the "vertical stud" (VSS). Figure 16.3 show the typical layout of the horizontal stud pot. The "horizontal" notation refers to the electrical connection by means of steel studs to the anodes. The horizontal studs enter the anode mass from the sides. The "green anode paste" is poured into the top of an open end steel casing and baked by cell heat. In effect, there is a continuous anode without the need for replacement as in the prebake operation. As a stud comes close to the cell bath it is removed. To remove the stud, the pot hood doors are opened and the steel channel containing these studs is forcibly removed.

16.2 Process Control Operation

Both particulate and gaseous air pollution control aspects must be considered. Fluorides, the gaseous constituent of primary interest, are soluble in water and also can be reacted with solids. Particulates consist of alumina dust, condensed metallic fumes and hydrocarbon tars (Soderberg).

The varying composition and wide spread of particle sizes of the particulate matter have led to the application of several types of control equipment. Historically, cyclones and wet scrubbing towers were the first devices used. Electrostatic precipitators, baghouses, medium energy wet scrubbers and dry reactor/baghouses are in current use.

Control methods for aluminum reduction cells include the following:

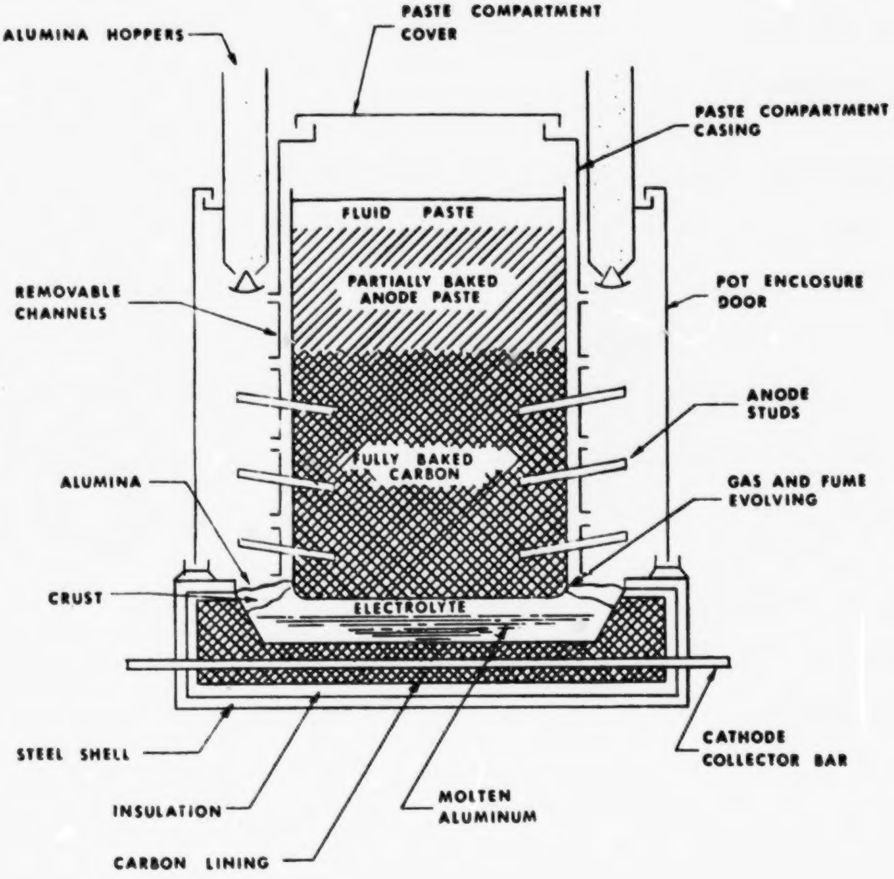

ALUMINA HOPPERS
PASTE COMPARTMENT COVER
PASTE COMPARTMENT CASING
FLUID PASTE
PARTIALLY BAKED ANODE PASTE
REMOVABLE CHANNELS
POT ENCLOSURE DOOR
ANODE STUDS
FULLY BAKED CARBON
ALUMINA
GAS AND FUME EVOLVING
CRUST
ELECTROLYTE
STEEL SHELL
CATHODE COLLECTOR BAR
INSULATION
MOLTEN ALUMINUM
CARBON LINING

FIGURE 16.3 HSS SODERBERG CELL

Wet Scrubbers - Spray towers can remove a high percentage of hydrogen fluoride since this contaminant is highly soluble in water. These devices, however, have a poor collection efficiency for fine particulates. Recent improvements include a floating-bed type of wet scrubber on horizontal Soderberg cells. This type of scrubber tends to overcome the problem of tar fouling that occurs in scrubbers with stationary packings.

Electrostatic Precipitators - Wet electrostatic precipitators are beginning to be used in controlling reduction cell emissions. These include vertical counterflow precipitators employing plywood collection plates which are irrigated with a falling film of water supplied from troughs at the top of the plates. Another application utilizes continuous spray washing of the collection plates and discharge electrodes.

Reactor/Baghouse - The method consists of the chemisorption of hydrogen fluoride on a finely divided alumina and removal of the sorbed fluoride by means of a fabric collector. Particulate fluorides are also removed by simple filters. The system requires effective local exhaust hooding on each pot. Particulate emissions as low as 3 pounds of hydrogen fluoride per ton of aluminum produced are claimed. Contamination of liquid streams and solid waste disposal problems are avoided and spent alumina from the collector system is recycled to the pots and the sorbed fluoride is added to the cryolite make-up.

Roof Monitor Scrubber. - In this procedure gases and dust are allowed to enter the workroom atmosphere. Large exhaust blowers at the ceiling induce an inward flow of outside air, through open louvres on the outside walls of the building, across the cells and into an overhead exhaust system to the gas cleaning equipment, usually wet scrubbing.

16.2.1 HSS

In order to trap the fumes escaping from the pots, hoods are usually used to capture most of the pot emissions (see Figure 16.4). From the hood, gases and particulates are ducted to various emission control equipment. Hoods do not capture all of the pot effluents. This is largely due to the need to open the hoods for pot maintenance, charging, anode replacement, and aluminum tapping. Pots designed for crust breaking and charging in the middle between anode rows are usually equipped with hoods which are only opened for anode replacement and metal tapping. Typical hood exhaust flow rates range from 2,000 to 4,000 cfm per pot.

A few prebake pot lines in the United States do not use hoods. All of the pot line effluent and room ventilation air passes through roof monitors, where the emission control equipment is located. Room ventilation air is regulated by adjustable louvers located in the building wall and situated to minimize worker exposure. Under certain wind conditions, this ventilation scheme allows pot line effluents to escape through building openings instead of through the monitors. Another scheme is to have the ventilation air enter through floor gratings. The air then passes up through the floor by each cell and out the monitors. Figure 16.5 illustrates these systems. Large amounts of air must be handled by control equipment (30,000 to 60,000 cfm per cell). Monitor controls are usually filament mats or screens wetted by water sprays. Gaseous fluoride collection efficiency is reported at 60 to 70 percent. Efficiencies for particulate collection have not been reported.

Factors which may influence emissions from the prebake pot lines include:

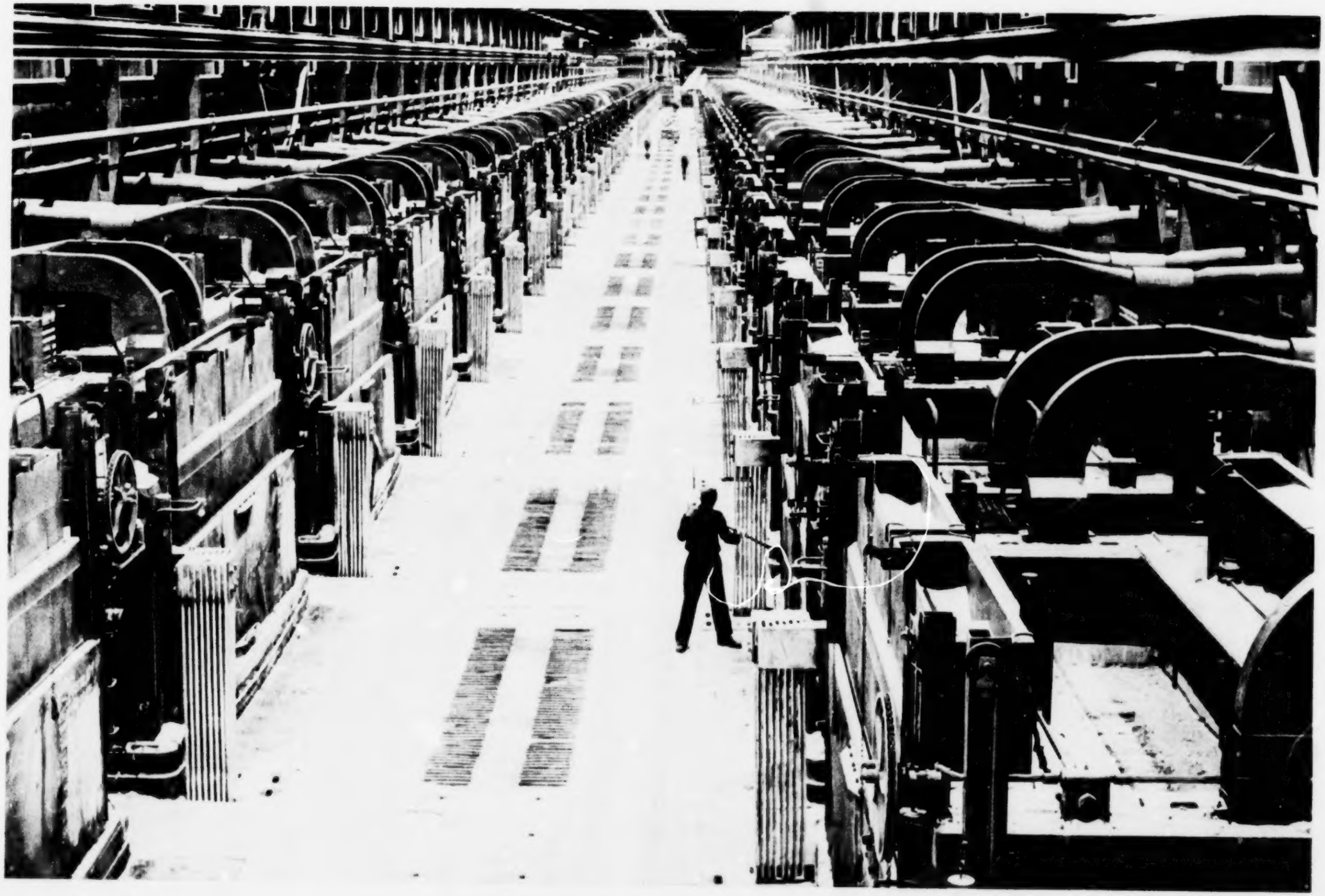


FIGURE 16.4 TYPICAL HSS POT(S) WITH HOOD(S)

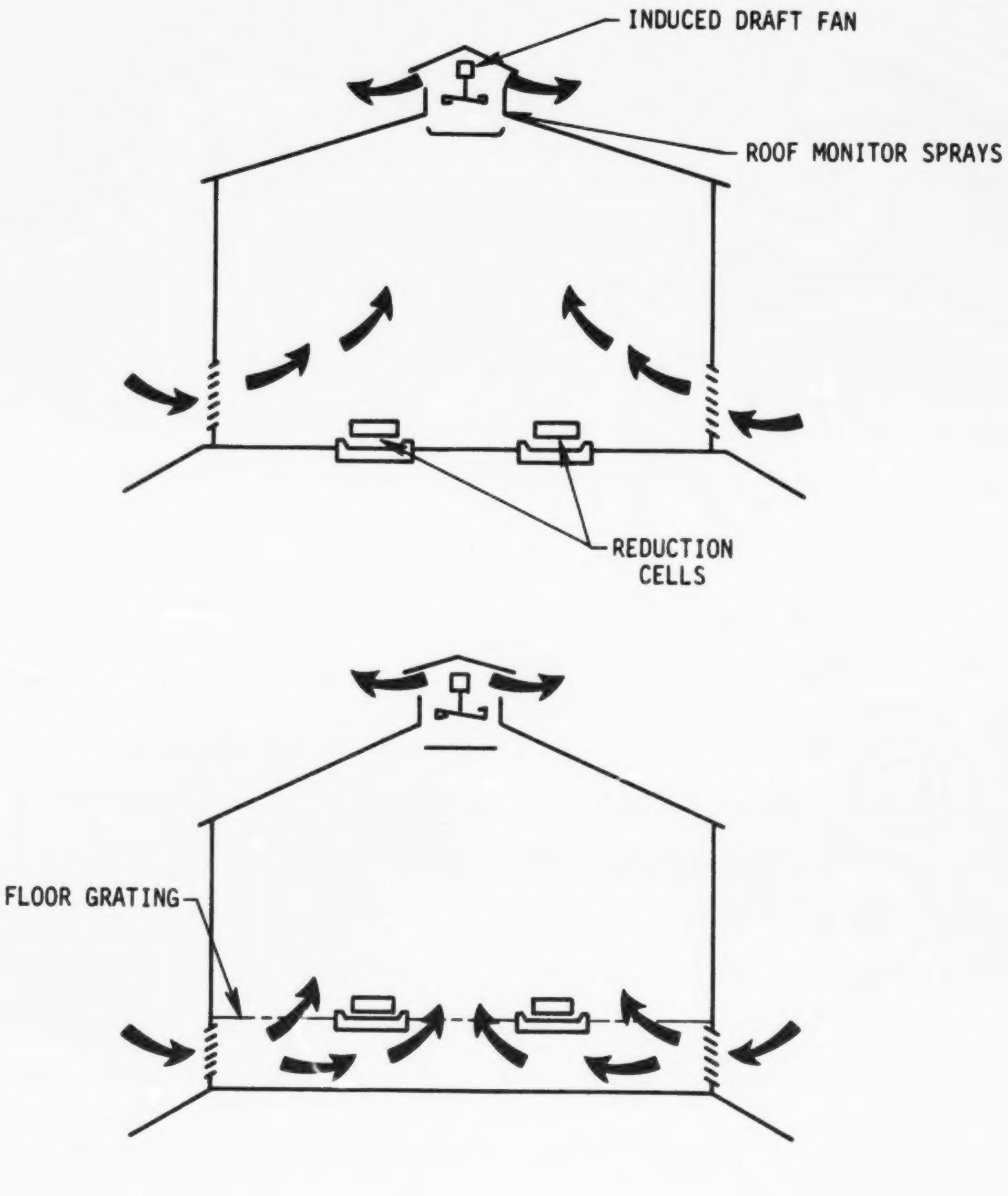

INDUCED DRAFT FAN
ROOF MONITOR SPRAYS
REDUCTION CELLS
FLOOR GRATING

FIGURE 16.5 ROOM COLLECTION SYSTEM SIDEWALL AND BASEMENT ENTRY

1. Adequacy of control equipment,
2. Maintenance and operation of equipment,
3. Anode effects,
4. Bath composition,
5. "Sick pots",
6. Charging frequency.

Various types of control equipment have been used for recovery of particulate and gaseous emissions from prebake cells. Tables 16.2 and 16.3 compare these different types of control equipment, their efficiencies and operating conditions.

Multiple tube cyclones are applicable to prebake operations since there are no tars in the gases to plug the equipment.

Reactor/baghouse systems have an advantage in that they remove both gaseous and particulate fluorides. The recovered effluents can be reused in the reduction process. The coated filter dry scrubber has shown efficiencies of 98 percent for solids and 90 percent for gaseous fluorides. This process involves the injection of finely ground alumina into the gas stream. The alumina forms a coating on the fabric bags and absorbs hydrogen fluoride passing through it.

Wet spray scrubbers are the most common type of control equipment used in aluminum reduction plants. Efficiencies are high for gaseous fluorides but lower for particulates. Particulate recovery can be greatly increased by preceding the scrubbers with small diameter cyclones. In prebake pot lines, spray scrubber gas volumes can range from 38,000 to 630,000 acfm.

TABLE 16.2

EFFICIENCIES OF CONTROL EQUIPMENT IN CURRENT USE FOR PREBAKE POTLINE EFFLUENTS

	Reported and Derived Efficiencies (%)		Operating Conditions	
Primary Collection	Particulate	Fluoride Gas	HP/MCF	Gal/MCF
Multiple Cyclone	77.9 to 85	-	0.8 to 1.6	
Fluid Bed Reactor/Baghouse	91.8 to 98.3	99.2 to 99.5	4.4	-
Coated Filter Reactor/Baghouse	98	76 to 92	1.5	-
Injected Alumina Reactor/Baghouse	98	98	1.5	-
Dry Electrostatic Precipitator	89 to 98	-	0.26 to 0.68	-
Spray Tower	80	88.9 to 98.4	0.4 to 0.9	1.7 to 10
Secondary Collection (No Primary Collection)				
Spray Screen	50	93	0.15 to 0.25	1.3 to 10
Crossflow Packed Bed (3 ft. Bed)	87	93	0.5	10

TABLE 16.3

ESTIMATED EFFICIENCIES OF CONTROL EQUIPMENT APPLICABLE TO PREBAKE POTLINE EFFLUENTS

	Estimated Efficiencies (%)		Operating Conditions	
Primary Collection	Particulate	Fluoride Gas	HP/MCF	Gal/MCF
Baghouse	98 to 99	-	1.6	-
Wet Electrostatic Precipitator	90 to 99	-	0.66 to 1.36	5 to 10
High Pressure Spray Screen (3 Stage)	93	98	6.1	26
Wet Centrifugal	92 to 97	85 to 92	2.0 to 3.2	6 to 10
Venturi	96	99	9.0 to 10.0	6 to 10
Wet Impingement	96 to 97	90	1.9 to 3.1	6 to 10
Orifice Type	93	96	3.3	6 to 10
Crossflow Packed Bed (5 ft. Bed)	87	98	1.5 to 1.8	10+
Secondary Collection (No Primary Collection)				
High Pressure Spray Screen (1 Stage)	82	95	2.0	5 to 10
Floating Bed	70	87 to 95	0.3 to 1.0	3 to 10
Secondary Collection (With Primary Collection)				
High Pressure Spray Screen (1 Stage)	82	95	2.0	5 to 10
Spray Screen	45	93	0.15 to 0.25	10
Crossflow Packed Bed (3 ft. Bed)	87	93	0.5	10
Floating Bed	70	87 to 95	0.3 to 1.0	3 to 10

Spray rates are from 2 to 10 gallons of liquor per 1000 cf of gas.

Fluidized bed reactors have shown good success in controlling aluminum plant effluents. Gaseous and particulate fluorides from reduction cells pass through a fluidized bed of finely divided alumina particles in the Alcoa Process 398, (Figure 16.6). The particulate, including alumina bed particles, are removed from the gas stream by fabric collectors located above the bed. Gaseous fluorides react with the bed-forming aluminum fluoride. The filter bags are cleaned periodically by reversing the gas flow. The accumulated filter cake falls back into the bed. Alumina is fed into the bed on one end and the reacted bed material is removed from the other end. The reacted bed material is conveyed to the pot lines for use in the cells. Table 16.4 shows the performance of this scrubbing scheme. It has been reported that the process should leave no visible plume. With this process there is no solid or liquid waste. Pollutants are captured and returned for reuse. Alumina particulates become charge to the pots and the adsorbed fluorides are reincorporated in the cell electrolyte.

16.2.2 VSS

Because of the baking of the anode paste during pot operation, hydrocarbons are emitted in addition to other pollutants normally associated with aluminum reduction. Tars cause a major problem in effluent control since they tend to clog and gum up some types of control equipment intended for particulates and fluorides.

In the VSS pot, the studs are in a vertical position. A metal skirt is attached to the bottom of the anode jacket to effectively trap cell effluents. The skirt reaches to the crust, thereby allowing little

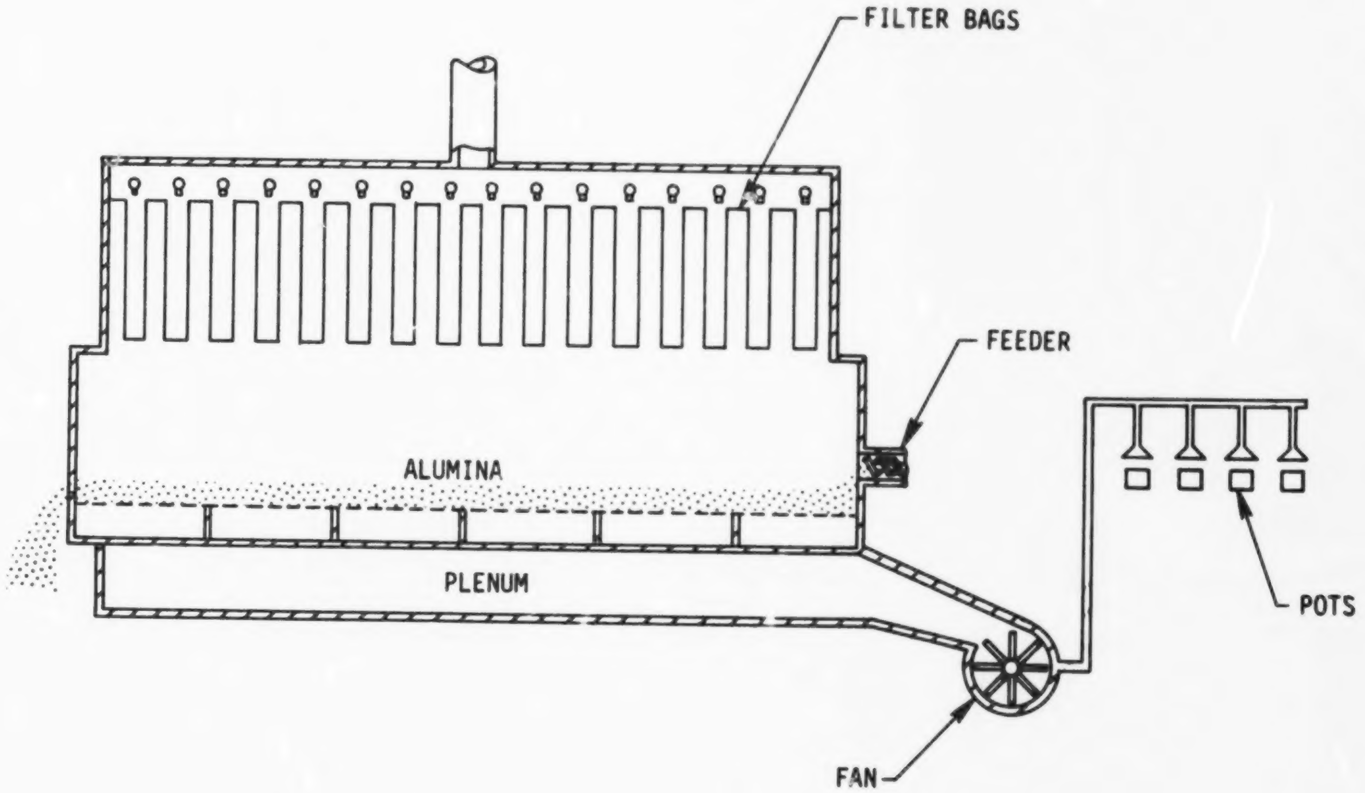

FILTER BAGS
FEEDER
ALUMINA
PLENUM
POTS
FAN

FIGURE 16.6 ALCOA 398 REACTOR

Table 16.4 FUME CONTROL PERFORMANCE OF ALCOA 398 SYSTEM

	REACTOR EMISSIONS lb/ton Al		ROOF VENT LOSS lb/ton Al		TOTAL PLANT	
	Total F	Total Particulate	Total F	Total Particulate	Total F	Total Particulate
Plant 1 - Average	0.36	.14	1.48	2.95	1.84	3.09
Range	0.09 to 1.03		0.55 to 2.56	1.95 to 3.77	0.64 to 3.59	2.09 to 3.91
Plant 2 - Average	0.37	1.41	1.76	4.10	2.13	5.51
Range	0.02 to 2.59		0.55 to 2.95	1.95 to 9.33	0.57 to 5.54	3.36 to 10.74
Plant 3 - Average	0.75	4.54	0.97	9.64	1.72	14.18
Range	0.05 to 3.96		0.68 to 1.20		0.73 to 5.16	

dilution air to mix with the effluent gases. Burning the hydrocarbons in the effluent gases reduces their concentration up to 97 percent, i.e., from about 3 to 0.1 percent by volume. This control method has the added advantage of converting fluoridated carbon compounds to simpler fluoride gases. Each pot has its own burner. Pot fumes from approximately 15 cells are collected and exhausted to control equipment. Cell burners convert effluent hydrocarbons to CO_2 and water vapor. The flame burns continuously when the cell is operating properly.

Variations in pot operation can cause the flame to extinguish unless ignitors or auxiliary fuel is used. An average of 5 to 10 percent of the burners on a pot line may be out at any instant which allows unburned hydrocarbons to enter control equipment downstream intended for particulate and fluoride control. Main combustion variables are hydrocarbon concentrations of the effluent gases, and the amount of combustion air supplied to the burners. Combustion air quantity is regulated by the shape, size and location of the air inlet opening. This duct between the skirt and burner should be large enough to permit a sufficient flow even when the bath splashes.

For particulate control after hydrocarbon combustion, cyclones have a collection efficiency of only about 40 to 50 percent.

Reactor/baghouse control equipment as well as scrubbers are in use with vertical stud Soderbergs. The dry process requires self-supporting combustion burners and gas cooling to $275^{\circ}F$ prior to the fluid bed. Chapter 16.1.2, particularly Tables 16.2 and 16.3, is generally applicable.

In VSS operations, crust breaking and pot charging are conducted outside of the gas collecting skirt, releasing some effluents to the pot room. The top of the anode casing releases a visible amount of heavy hydrocarbons and some sulfur dioxide from the baking of the paste. These emissions are not captured by the pot ventilation system and escape the building through the roof monitor.

16.2.3 HSS

Due to the baking of the anode paste during pot operation, hydrocarbons are emitted in addition to other pollutants normally associated with aluminum reduction. Tars cause a major problem in effluent control since they tend to clog and gum up ducts and many types of control equipment.

Capture of horizontal stud Soderberg pot effluents is extremely difficult because of the large emission potential during crust breaking, pot stirring, stud removal, and other routine operations which require access to the surface of the pot. At these times the hoods must be open.

Frequent opening of doors presents several serious problems affecting the capture of pot effluents. When the door is open the substantial thermal head carries the effluents out of the control zone of the hoods. With frequent use the doors warp, become bent, and otherwise fit poorly. High pot temperatures can warp the doors, door support frames and the pot body.

It is significant that HSS pots probably have the poorest capture efficiency of the three types of aluminum smelting pots. This is due to the doors being open for longer periods of time to carry out the necessary pot operations.

Effluent recovery is a complicated problem. A gas skirt cannot be connected to the anode casing because the casing shell is composed of removable sections that are changed as the anode is consumed. Hoods are suspended above the cells entraining large volumes of dilution air. The resulting dilute effluent gases will not support combustion and with burning impossible, ducts and control equipment are fouled by the tars. Cyclones and baghouses would be rapidly clogged and electrostatic precipitator plates must be flushed with water to remove accumulated tars and other particulates. High velocity spray scrubbers are usually used but even they tend to clog without mechanical collectors or combustion units because the tars tend to resist wetting.

A floating bed scrubber (Figure 16.7), however, has been used to overcome the problem of tar fouling. The bed consists of polyethylene spheres and during operation, liquor flows down the floating bed, absorbing gases and cleaning the spheres. The collection efficiency of total fluorides (particulate and gaseous) is better than 95 percent. Soluble fluorides are recovered with better than 98 percent efficiency.

16.3 Enforcement Procedure

The objective of aluminum reduction plant inspection is to establish compliance with fluoride, sulfur dioxide, and particulate emission regulations. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design levels.

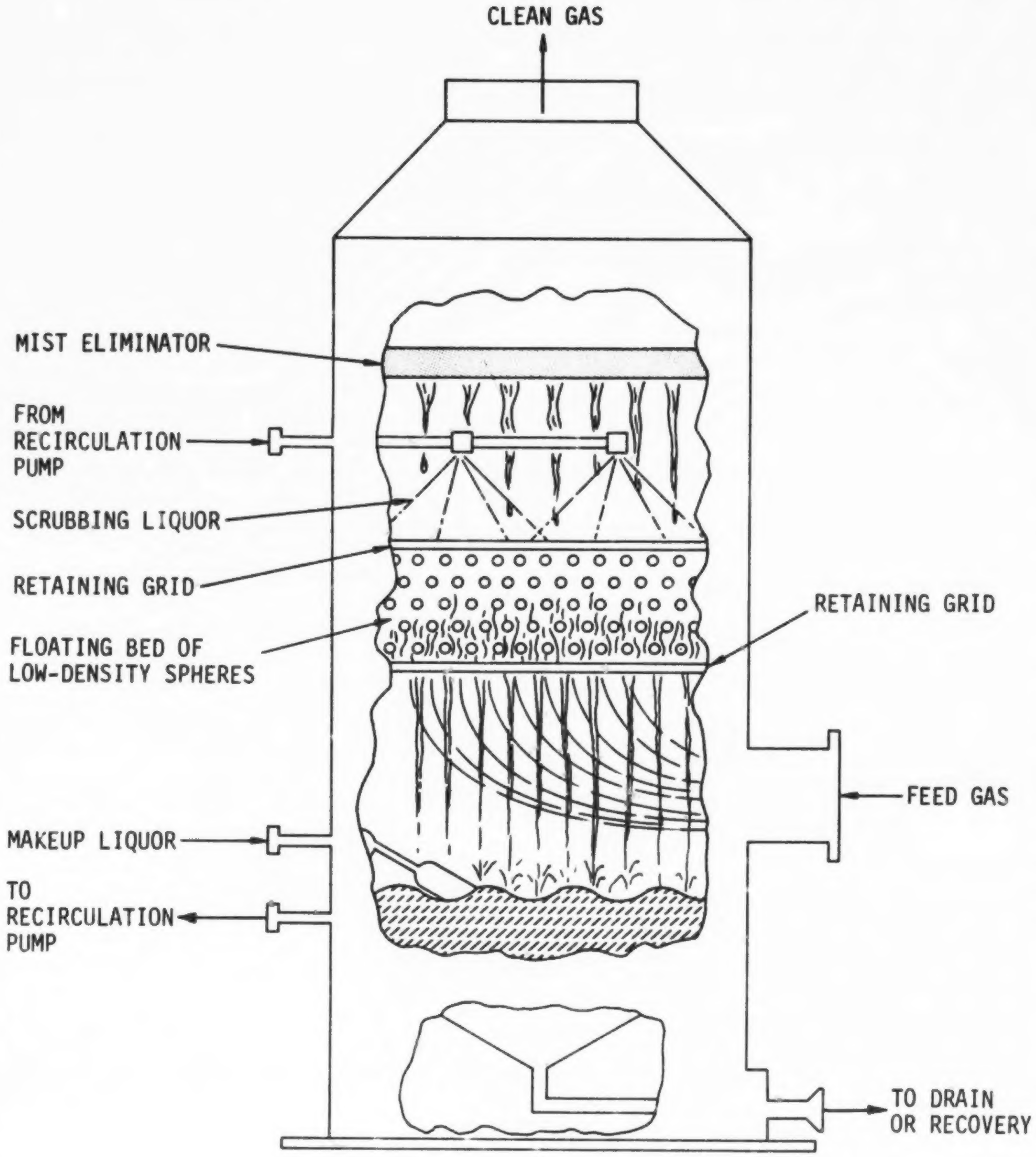

CLEAN GAS
MIST ELIMINATOR
FROM RECIRCULATION PUMP
SCRUBBING LIQUOR
RETAINING GRID
RETAINING GRID
FLOATING BED OF LOW-DENSITY SPHERES
FEED GAS
MAKEUP LIQUOR
TO RECIRCULATION PUMP
TO DRAIN OR RECOVERY

FIGURE 16.7 FLOATING BED SCRUBBER DEVELOPED FOR HORIZONTAL STUD SODERBERG CELL EXHAUSTS

Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

Pot lines will have a control booth in the plant for monitoring purposes. The enforcement official should have little difficulty assessing the current operating status of the pot line by observing the many recorders, gauges, and the log sheets which are normally kept.

The contaminants of most concern from aluminum reduction plants are fluorides and particulates. In general, the fluoride emissions occur continuously, while particulate emissions are highest when there is some activity at the pot such as crust breaking, charging, siphoning, or responding to an anode effect.

Aluminum pot lines are operated continuously and are rarely taken out of service. The Inspector's Worksheet indicates the operating variables which need to be recorded during the enforcement official's visit. Aside from the data indicated on the worksheet, the enforcement official should observe certain operations and plant practices.

The enforcement official should observe the pot activities. It should be pointed out that these activities usually occur during the early part of the work shift. Therefore, it is suggested that the enforcement official arrive at the plant near the beginning of a work shift to carry out an effective inspection.

At those plants which use hoods on the pots the official should check for leaks and adequacy of the exhaust volume. He should walk completely around several of the pots, selected at random, and check for visible particulate escape when the doors on the hood are closed. If any particulate matter escapes the hood, it is an indication that the exhaust volume is not adequate for this particular cell or that the exhaust volume is not in balance with other pots on this line.

When the doors are open on the hoods for activities such as crust breaking, charging, siphoning, or controlling an anode effect, the enforcement official should observe how much of the plume escapes the hood system. Plant operators can increase the exhaust volume of any pot by damper adjustments.

It is recommended that the enforcement official visit at least two lines during his visit. While observing the plume leaks and balance on selected pots, the enforcement official should also note the number of anode effects which will occur on this particular line during this inspection. All aluminum plants have lights or bells on each pot which, when lit or ringing, will denote an anode effect. A walk up each aisle of a pot line will indicate the number of anode effects that exist on this line. Anode effects cause the highest particulate emissions. Emissions will continue at an elevated level until the anode effect is controlled. Anode effects are controlled both automatically and manually. Whatever the plant method for responding to an anode effect, the enforcement official should note the time it takes to respond and return the pot to normal operation.

The enforcement official should note the number of doors left open and unattended on a particular pot line. From visit to visit the enforcement official will develop a "feel" for the amount of emission escaping to the roof monitor based on the visibility inside the pot room.

Some plants may not use hoods on the pots to control emissions. In these plants, the enforcement official should check to verify that the plume rises to the roof monitor instead of escaping the building through the louvered walls. If it does not go to the monitor, it is an indication that the emissions may be excessive.

Particulate and fluoride emissions from aluminum reduction pot lines will depend on the adequacy of the design maintenance, and operation systems and the pots. Scrubbers and/or dry adsorption baghouses may be used to reduce particulate and fluoride emissions from pot lines. There is little data that an enforcement official can gather relative to the operation of the air pollution abatement systems. The enforcement official should, however, note the pressure drop on scrubber and the scrubber water flow rate, if available. At some plants, review of recorded pH control data will give an indication of scrubber effectiveness. Abnormally low pH is an indication of plant upset with attendant elevated fluoride emission potential.

The enforcement official should ascertain that the scrubber is operating and that water is circulating. Because of freezing temperatures, some plant operators will not or cannot operate their scrubbers at low ambient temperatures. Instead, the units are turned off, the water is drained and the exhaust gases pass uncontrolled to the atmosphere. If this occurs, the enforcement official should take proper action. It is possible that these exhausts will have been diverted to standby control devices.

For dry adsorption processes, it is likewise difficult to ascertain that the control equipment is operating satisfactorily. In the dry adsorption process, reactant must be charged to the control device in order to control fluoride emissions. Some devices pipe the powdered reactant directly into the duct while one process has a fluidized bed of alumina. If reactant is not in the control system, then no fluoride reduction is taking place. The enforcement official should observe the entire dry adsorption process and determine that the reactant is being used. Baghouses are used in the dry adsorption system. Plants will generally have manometers and continuous recorders on these baghouses. A check of the manometer and a review of recorded pressure drop data will indicate the baghouse operability.

If desired, the enforcement official can make quick determinations for hydrogen fluoride, sulfur dioxide, and particulate emission levels. (See Part VII).

With the mass rate and sulfur content of the anodes, an estimate of SO_2 mass emissions can be computed. It should be pointed out that many state regulations restrict sulfur emissions from the entire smelter and not just the pot room. For determining compliance with the regulations, sulfur emissions from each operation must be summed.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of control equipment stack plumes. If in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine point(s) of origin

INSPECTORS WORKSHEET

FOR ALUMINUM REDUCTION PLANTS

GENERAL

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

Type Plant: VSS, HSS, Prebake________________

OPERATING VARIABLES

Aluminum Production Rate______tons/day

No. of lines running________________

No. of pots running today____________

Anode, sulfur content_______________%, Usage_____________ tons/day

Average anode effects per pot line per day_______

Cryolite addition rate__________lbs/1,000 lbs of Aluminum

Flow rate per cell this line________scfm; Line No.________

ABATEMENT EQUIPMENT

Parameter \ Unit	1	2	3	4	5	6	Average
Particulate efficiency %							
F^- efficiency %							
Pressure drop, in. H_2O							
Scrubber water flow rate, gpm							
Dry adsorption feed rate, lb/hr							
Flow rate, scfm							
Inlet temp, °F							
Opacity, %							

ACTUAL EMISSION DATA

Particulates__________lb/ton of Aluminum

Fluorides (gaseous)______________lb/ton of Aluminum

Sulfur Dioxide ppm______________, lb/hr_____________

Tested by:____________

Date:____________

GENERAL OBSERVATIONS

____

____

____

____

____

Time In_____________

Time out______________

and require corrective action.

Systems and equipment for controlling aluminum reduction emissions will require constant upgrading in the years ahead to meet increasingly stringent emissions standards. Emissions which may now range from 40 to 50 lbs/ton aluminum processed will have to be reduced to something like 15 lbs/ton and #1 Ringelmann. Bag filters and improved electrostatic precipitators may be the only types of control systems that will help to realize this goal. Such design improvements as larger pot capacities, automated ore feeding, and roof scrubbers should also help to achieve these goals.

Much of the inspector's function will be to help assure that compliance schedules are met, that control systems are conscientiously operated and maintained, and plant facilities are operated and maintained in a manner which takes into account air pollution control, and prevents environmental damage in the vicinity of and downwind from the plant.

The enforcement official should complete the Inspector's Worksheet.

17. CAST HOUSE OPERATIONS

This is a minor but highly visible source of particulate emissions and chlorine. Emissions are mainly dependent on control system design and plant operational practices.

17.1 Process Description

The metal siphoned from the pots is transported from the pot room to another part of the plant where it is then poured into an alloying furnace. The alloying furnace is a fuel-fired reverberatory furnace, either rectangular or circular. Metal is usually poured into the furnace through a funnel port on the side.

Scrap may be charged into the alloying furnaces. If scrap is charged, it is often done prior to "pot" metal additions so that the excess heat in the pot metal can be utilized to melt the scrap. Pot metal is at 1,750°F while alloy furnace operation is at 1,400°F to 1,500°F.

The circular units have removable roofs so that scrap is top-loaded. The rectangular units are charged through side doors. Some rectangular units have external hearths into which scrap can be charged into the molten bath without direct flame impingement.

After the furnace has been partially filled with scrap and pot metal, it is sampled to establish analysis. Additions are made to conform to alloy requirements. In some plants partial alloying is done in the pots, particularly elements such as copper, silicon, iron, and manganese. If not, then they are added in the alloying furnaces as are zinc and magnesium.

During the alloying process the bath may be "blown" with nitrogen, chlorine gas, chlorine-nitrogen or chlorine-nitrogen-carbon monoxide mixtures to carry to the surface suspended oxides and to degas.

After alloying is finished, the furnace is again deoxidized and degassed with chlorine, or other gases, or by use of chloride fluxes. It is then skimmed. The finished alloy is then laundered into holding furnaces.

The holding furnace is a rectangular fuel-fired reverberatory furnace. It is usually quite shallow since temperature in the bath must be closely controlled.

Final degassing and deoxidizing is accomplished, temperatures are stabilized, analysis is checked, and the metal is poured into:

1. Billets,
2. Rolling ingots,
3. Sows,
4. Casting ingots,
5. Pigs.

Various pouring systems are used. Rolling ingot and billet are cast in continuous casters or direct chill casters and sows are poured from ladles filled at the furnace and taken to the pouring floor where the cast iron sow molds are lined up for filling. Casting ingot and pig is either poured into conveyors equipped with cast iron molds or into continuous casting units.

The furnaces are skimmed as necessary to remove drosses. The drosses on the surface interfere with heat transfer and must be removed before they get so thick as to allow "thermit reaction" to occur on the bath or to reduce heating efficiency. The drosses are skimmed into skim pans and in some plants these pans are taken to a dross barrel where the drosses are heated and spun in a refractory lined drum. The excess metal drains and is poured off and the remaining dross is dumped into a pan or onto a conveyor and taken to a cooler, then to tote boxes and indoor storage.

In some plants the skim pans are taken to a dross cooling area where they are dumped, manually or mechanically spread and hosed down to cool, and then collected and taken to indoor storage. Later, the drosses are loaded into trucks or railroad cars for shipment to other plants for processing.

17.2 Process Control Operation

The operations in the cast house generate gaseous and particulate emissions. Mechanical operations such as transfer of metal, scrap charging, stirring, and skimming may also result in emissions.

If scrap is dirty, i.e., oily, painted, or laquered, carbonaceous effluents may be generated. In the furnaces where scrap is charged in the melting zone much of the smoke is burned but in the "open-hearth" charging furnaces pickup hoods must be in place and connected to control equipment to prevent emissions

During alloying few emissions occur except when magnesium is not properly handled. This can create a magnesium fire with attendant emission of aluminum and magnesium particulates.

During degassing or during the process for removing suspended solid oxides from the melt (deoxidizing) gases or salt chemicals are fluxed into the bath. This generates emissions of fine particulates and gases. When chlorine or chlorine-nitrogen is used there will be emissions of aluminum chloride and chlorine, but when chlorine-nitrogen-carbon monoxide or tri-gas is used there is less visible emission. The chlorine-nitrogen or tri-gas emissions will contain very little chlorine and when nitrogen is used, only particulate emissions result.

The use of hexachlorethane, aluminum chloride, or magnesium chloride involves the mechanical insertion of the powdered salts into the melt using iron tools. The salts react and vaporize. They react with dissolved gases and suspended solids to bring them to the surface, which will result in the formation of copious visible emissions. The chlorides will react on cooling and mixing with atmospheric moisture to form HCl which can be detected by its pungent odor.

If the skim pans are not removed quickly to further process activity, the aluminum will burn, resulting in the emission of large quantities of aluminum oxide. These thermally-generated particulates, less than 0.5 microns, are in the particle size range of maximum light scattering.

Pouring processes may result in discharge of steam plumes from the cooling operation.

The gaseous additives flow rates are usually controlled by flowmeters and pressure gauges and the salt additions are weighed but reaction rates are not consistent.

Air pollution control practices vary widely at cast houses, depending principally upon the emission potential and the gas volume to be treated. Scrubbers or baghouses are the usual control devices used.

17.3 Enforcement Procedure

The objective of cast house operation inspection is to establish compliance with particulate emission regulations. In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to the physical plant inspection. Production levels and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

The cast house may have a control booth near the units for monitoring. The enforcement official should have little difficulty assessing the current operating status of the furnaces by observing the many recorders, gauges and logs which are normally kept.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of control equipment stack plumes and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine the point(s) of origin and require corrective action.

18. CRYOLITE MANUFACTURE AND RECOVERY

The potential emissions are particulates. This is a minor source.

18.1 Process Description

Cryolite is essential in the production of aluminum since it acts as the solvent in which powdered alumina is dissolved in a bath and electrically reduced to molten aluminum.

$$Al_2O_3 + C \xrightarrow[\text{electricity}]{\text{cryolite}} Al + CO_2$$

Cryolite occurs naturally and is found in large enough quantities to mine only in Greenland. Most cryolite used today is manufactured or "synthetic".

In the process of aluminum reduction, fluorides are vaporized causing a depletion in the fluoride content to the cryolite electrolyte. Fluoride compounds which are rich in sodium are absorbed by the carbon cathodes of the pot. Aluminum fluoride, soda ash, fluorspar, and cryolite are added to the pots on an "as-needed" basis. About 40 to 80 pounds of cryolite must be added to the bath per ton of aluminum produced.

Because of the high value of the fluoride compounds captured in air pollution control systems and/or the pot linings, some primary reduction plants have facilities for recovering cryolite from pot linings and scrubber effluent.

When the carbon lining becomes decomposed and needs to be replaced (typical average pot life is 3 years), it is removed from the pot line and the lining is stripped from the steel shell. Outdoor storage of the pot linings may result in water pollution. If rain comes in contact with the fluoride laden linings, some of the fluoride will be washed away. Several aluminum plants have built concrete storage facilities with suitable drains and treat the rainwater discharge. The composition of the pot linings when taken off-line is:

Carbon	30%
Cryolite	30%
Alumina	25%
Fluorspar	5%
Sodium Carbonate	7%
Silicon Oxide	2%
Ferric Oxide	1%

To recycle, pot linings are crushed and ground to 80 percent minus 100 mesh and are reacted in a digester with sodium hydroxide. The slurry is further processed through a variety of thickeners and mixers where various chemical reagents are added to produce a slurry composed of Na_2AlO_2. The cryolite is precipitated in a carbonator by bubbling CO_2 through the solution which yields cryolite, Na_3AlF_6. The cryolite is then dried in a rotary diln and returned to the pot room. Kilns are usually fired with natural gas to prevent any contamination from other fuels in the "synthetic" cryolite.

Because of the economics involved in cryolite recovery, efficient air pollution control devices are used. Medium energy wet scrubbers are usually used. The slurry from the kiln scrubber is recycled directly into the thickener. Figure 18.1 illustrates the basic steps involved in cryolite recovery.

18.2 Process Control Operation

Two factors which influence emission levels from cryolite recovery operations are: capacity of plant and adequacy of the collection system. There are few operating variables at a cryolite plant which would affect air pollution emissions. The quantity of particulate emissions will be determined by the process weight rate of the kiln and the adequacy of the control equipment.

Process information available at cryolite recovery plants includes kiln temperature, feed rate, scrubber pressure drop, water flow rates, and tank levels. Little variation in operating conditions and emissions levels will be noted from day to day.

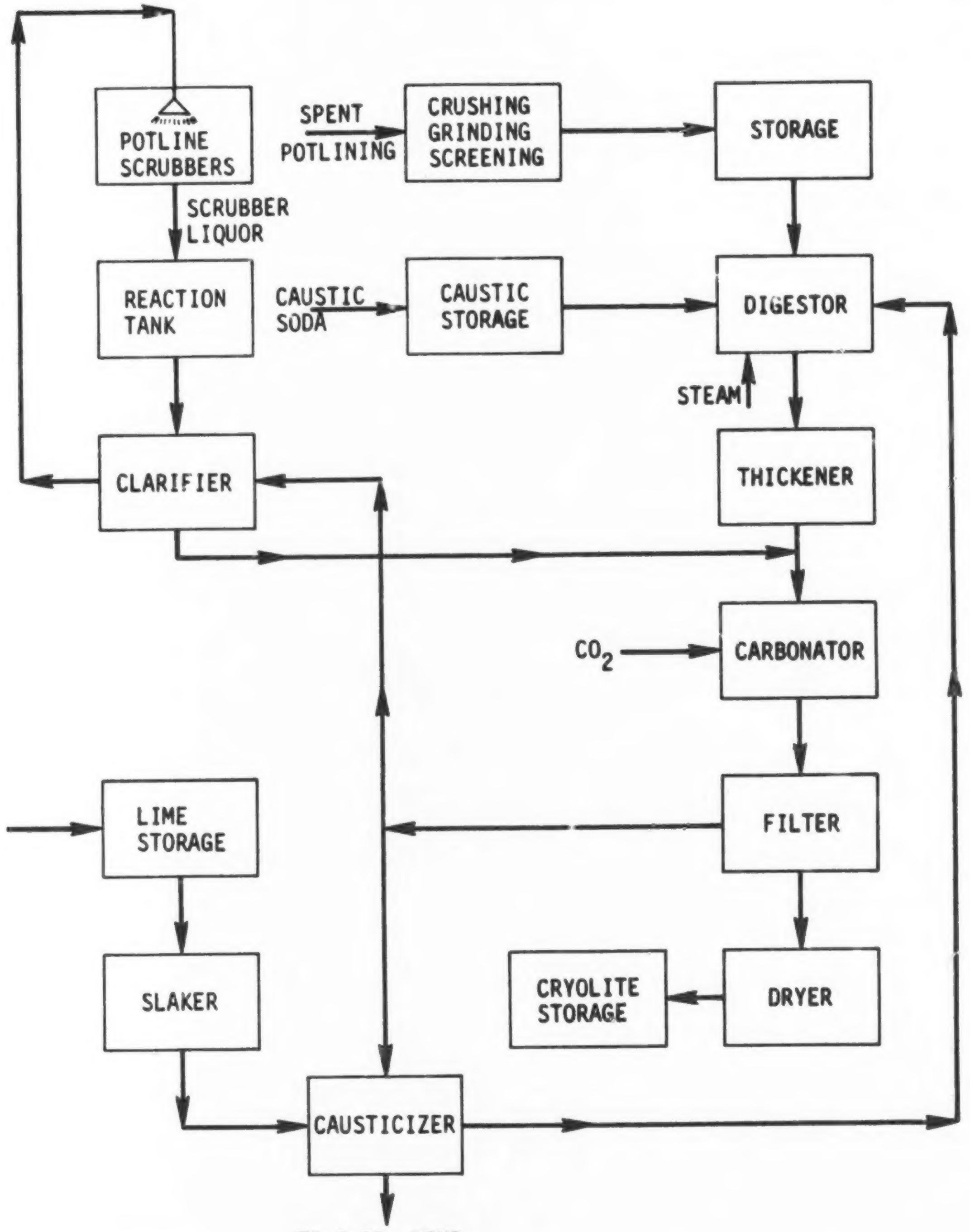

POTLINE SCRUBBERS
SPENT POTLINING
CRUSHING GRINDING SCREENING
STORAGE
SCRUBBER LIQUOR
REACTION TANK
CAUSTIC SODA
CAUSTIC STORAGE
DIGESTOR
STEAM
THICKENER
CLARIFIER
CO_2
CARBONATOR
LIME STORAGE
FILTER
SLAKER
CRYOLITE STORAGE
DRYER
CAUSTICIZER
TO $CaCO_3$ POND

FIGURE 18.1 CRYOLITE RECOVERY FLOW DIAGRAM

18.3 Enforcement Procedure

The objective of cryolite recovery operation inspection is to establish compliance with particulate emission regulations. In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both plant and emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to the physical plant inspection. Production levels and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

The plant may have a control booth for monitoring. The enforcement official should have little difficulty assessing the current operating status of the plant by observing the recorders, gauges and log sheets which are normally kept.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plumes and if in excess of allowable limits, take appropriate action.

INSPECTORS WORKSHEET

FOR CRYOLITE RECOVERY PLANTS

GENERAL

Plant Id.____________________________________

Date this inspection______________Date last Inspection____________

OPERATIONAL VARIABLES

Cryolite plant process rate_________ tons/day

ABATEMENT EQUIPMENT

Pressure drop, in. H_2O__________________

Scrubber flow rate, gpm__________________

Exhaust flow rate, scfm__________________

Particulate efficiency__________________

Inlet temp. °F_________________________

Opacity %______________________________

ACTUAL EMISSION DATA

Particulates_______________lb/hr

Tested by______________

Date__________________

GENERAL OBSERVATIONS

____

____

____

____

____

Time In________________________Time Out_________________________

Building openings should be observed for evidence of the escape of inadequately captured process dust and if noted, determine point(s) of origin and require corrective action.

19. ANODE AND CATHODE RECLAIMING

This is a minor potential source of particulate emissions and odors.

19.1 Process Description

Soderberg pots have a continuous anode and therefore the anode reclaiming operation is not associated with these operations. As stated in Chapter 16, the prebake plant manufactures the anode in a separate facility away from the pots. Most of the carbon in the anode is consumed during the reduction process. The prebake anodes have a life of about 10 to 20 days at which time the "butts" are removed and sent to the anode and cathode reclaiming center.

When the anode is first installed in a cell, the dimensions include a height of about two feet. When the butts are removed, the height has been reduced to about six inches. When the butts are extracted from the cell they are contaminated with alumina, aluminum fluoride, and cryolite. The operators try to knock off the laden material. After the anode is removed from the pot, residual crusty material is knocked off and returned to the pot.

The anode butts are carried to the anode and cathode reclaiming center where jack hammers and other devices are used to separate the steel studs from the remaining carbon block. Some plants use hydraulic presses. The spent carbon is ground and reused in making new anodes; the steel studs are returned for further cleaning and then reused in anode assembly.

The major source of emissions at an anode and cathode reclaiming center occur during the use of jack hammers which remove the carbon from the stud. Compared to other sources at an aluminum reduction plant, this is considered a minor source. None of the aluminum reduction plants control air pollution emissions from the anode and cathode reclaiming center.

Although all aluminum reduction plants have cathodes, not all plants recycle them. Once the cathodes have been removed from the pot line, they are taken to a separate building (reclaiming center) where cranes handle the steel jacketed cells. Some plants will use water, steam, and some chemicals to assist in the process of removing the carbon lining from the steel jacket. If water is used, there is the possibility of the release of ammonia and carbides. Particulate emissions and odors from the cathode reclaiming shop emanate during the handling of the large cathode. At best, this could only be considered a minor source of particulate emissions. The spent carbon may be returned to the anode shop for making paste or to cryolite reclamation.

19.2 Process Control Operation

There are no operating variables which affect air pollution emissions from this source.

19.3 Enforcement Procedure

Anode and cathode reclaiming shops are a minor source of air pollution emissions. Fugitive dust is generated during anode and cathode handling, but because of the frequency of these operations and the amount of particulate emitted, no further inspection is required at an anode and cathode reclaiming shop.

Interpretation of these observations is heavily dependent upon the pertinent regulations governing fugitive dust emissions. Since many of these plants are located on large plots of land, it may be important to discriminate between in-plant housekeeping problems and emissions which cross the property line.

PART III

COPPER SMELTING

Copper was first produced in the United States at Simsbury, Conn. in 1709. Further discoveries of ore deposits were made in Vermont in 1820 and in Michigan in the early 1840's. Extensive ore bodies were found in Arizona and Montana during the period from 1860 to 1880, and by 1880 smelter production from domestic mines had reached 30,000 tons per year. In 1906, the exploitation of the large, low-grade porphyry deposits in Utah was begun, and with the development of froth flotation concentrating technology in the early part of the century, low-grade deposits became economically attractive.

Today, virtually all domestic mining operations are conducted in seven states, producing 170 million tons of copper ore. Concentrates from this ore and imported concentrates are processed at 16 primary copper smelters with a total annual charge capacity of 9.2 million tons of copper concentrate, representing 1.8 million tons of copper. Table III-1 lists these 16 copper smelters and their locations and capacities.

Mineralogically, copper ores are divided into three ore groups: sulfide, oxide, and native. In the United States, sulfide ores comprise 85 to 95 percent of the total primary production. The deposits of the Lake Superior district (Lake Copper) are the only ones of economic importance in which metallic copper is the chief ore mineral. This native metal is very pure, containing 98 to 99 percent copper with small amounts of silver and minor quantitites of arsenic. Table III-2 lists the composition of the more important sulfide and oxide minerals from which copper is extracted.

These minerals are usually associated with siliceous and other minerals, so that most copper ores consist partly of one or more copper

Table III-1 U.S. COPPER SMELTERS
(Thousands of Short Tons Charge*)

COMPANY	LOCATION	CAPACITY
Asarco	El Paso, Texas	420
Asarco	Hayden, Arizona	420
Asarco	Tacoma, Washington	600
Anaconda Company	Anaconda, Montana	1000
Inspiration Consolidated Copper Co.	Miami, Arizona	450
Magma Copper Company		
Magma Division	Superior, Arizona	150
San Manuel Division	San Manuel, Arizona	403
Kennecott Copper Corp.		
Nevada Mines Division	McGill, Nevada	400
Chino Mines Division	Hurley, New Mexico	400
Ray Mines Division	Hayden, Arizona	420
Utah Copper Division	Garfield, Utah	1000
Phelps Dodge Corp.		
Douglas Smelter	Douglas, Arizona	1250
Morenci Branch	Morenci, Arizona	900
New Cornelia Branch	Ajo, Arizona	300
Tennessee Corporation		
Tennessee Copper Co. Division	Copperhill, Tennessee	90
White Pine Copper Co.	White Pine, Michigan	90+
Total		8293

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* Stated in tonnage of annual capacity for smelting materials that yield a product.

+ Thousands of tons of copper.

Table III-2 Common Copper Bearing Minerals

Mineral	Theoretical Formula	Cu(%)	S(%)
Chalcopyrite	$CuFeS_2$	34.5	34.9
Chalcocite	Cu_2S	79.8	20.2
Bornite	Cu_5FeS_4	63.6	25.6
Covellite	CuS	66.5	33.5
Malachite	$CuCO_3 - Cu(OH)_2$	57.3	0
Azurite	$2CuCO_3 - Cu(OH)_2$	55.1	0
Cuprite	Cu_2O	88.8	0
Chrysocolla	$CuSiO_3 2H_2O$	36.2	0

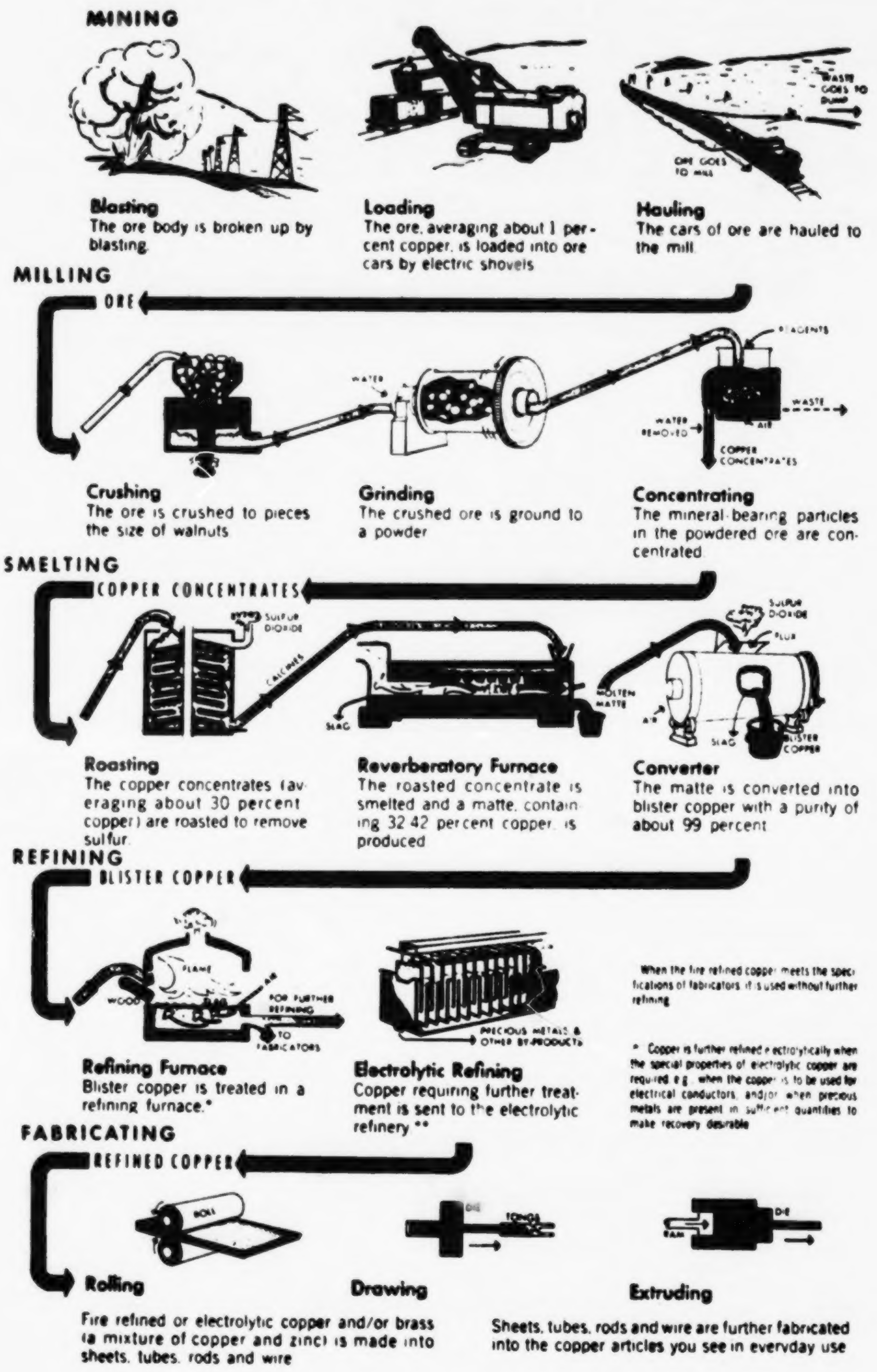
containing minerals and partly of earthy matter. The sulfide ores are also generally associated with iron sulfides. The type of copper ore and its tenor, i.e., percentage of copper content, determines the method of extraction.

There are two methods of copper extraction from concentrated ores:

1. Dry methods consisting of smelting followed by treatment of the copper-bearing mineral in a converter,
2. Wet methods consisting of leaching and precipitation or electrowinning of the copper from solution.

Leaching is the term applied to the process of recovering the valuable metal from an ore by dissolution with an aqueous solvent, leaving the gangue or waste material virtually unaffected. Subsequent recovery of the metal from solution is accomplished by chemical or electrolytic precipitation. For copper, these processes are limited largely to copper-bearing materials that, because of grade, composition or other consideration, are not amenable to concentration and pyrometallurgical extraction. Generally, hydrometallurgical methods are used to treat low-grade ores containing native copper, oxide, or mixed oxide-sulfide minerals because costs of other types of treatment are too high per unit of copper recovered. There are no air pollution problems associated with leaching itself, although as in other materials handling activities, the problem with fugitive dust is a recurring one.

Since most of the world copper production is extracted from low-grade sulfide ores, smelting is the dominant method of recovery of the metal. Figure III-1 shows the basic steps in copper production, one of which is the pyrometallurgical process of separating copper from the iron, sulfur, and gangue. The strong affinity of copper for sulfur and its weak affinity


MINING
WASTE GOES TO DUMP
ORE GOES TO MILL
MILLING
ORE
WATER
REAGENTS
WASTE
WATER REMOVED
AIR
COPPER CONCENTRATES
SMELTING
COPPER CONCENTRATES
SULFUR DIOXIDE
CALCINES
SLAG
MOLTEN MATTE
SULFUR DIOXIDE
FLUX
AIR
SLAG
BLISTER COPPER
REFINING
BLISTER COPPER
FLAME
WOOD
AIR
FOR FURTHER REFINING
TO FABRICATORS
PRECIOUS METALS & OTHER BY-PRODUCTS
FABRICATING
REFINED COPPER
ROLL
DIE
TONGS
RAM
DIE

Blasting
The ore body is broken up by blasting.

Loading
The ore, averaging about 1 percent copper, is loaded into ore cars by electric shovels.

Hauling
The cars of ore are hauled to the mill.

Crushing
The ore is crushed to pieces the size of walnuts.

Grinding
The crushed ore is ground to a powder.

Concentrating
The mineral-bearing particles in the powdered ore are concentrated.

Roasting
The copper concentrates (averaging about 30 percent copper) are roasted to remove sulfur.

Reverberatory Furnace
The roasted concentrate is smelted and a matte, containing 32-42 percent copper, is produced.

Converter
The matte is converted into blister copper with a purity of about 99 percent.

Refining Furnace
Blister copper is treated in a refining furnace.*

Electrolytic Refining
Copper requiring further treatment is sent to the electrolytic refinery.**

* When the fire refined copper meets the specifications of fabricators it is used without further refining.

** Copper is further refined electrolytically when the special properties of electrolytic copper are required, e.g., when the copper is to be used for electrical conductors, and/or when precious metals are present in sufficient quantities to make recovery desirable.

Rolling

Drawing

Extruding

Fire refined or electrolytic copper and/or brass (a mixture of copper and zinc) is made into sheets, tubes, rods and wire.

Sheets, tubes, rods and wire are further fabricated into the copper articles you see in evervday use.

FIGURE III-1 BASIC STEPS - COPPER ORE TO FINISHED PRODUCT

for oxygen, compared with iron, sulfur and other base metals of the ore, form the basis for the three primary steps in smelting - roasting, reverberatory furnacing, and converting. Although particularly adapted to the reduction of sulfide ores, high grade oxide ores may be used as part of the charge to the furnace, or if siliceous, may be fed direct to the converters as fluxing material.

The treatment of the Lake Copper ores of the Lake Superior district departs from the general smelting process, in that the matte-forming and converting stage are combined and, consequently, the smelting process is more akin to copper refining and is not a part of this manual.

Figure III-2 illustrates the three primary steps in copper smelting and the materials entering and leaving the system at each step. Figure III-3 shows representative quantities involved in each step. Figure III-4 is a simplified flow diagram of the smelting process with emission points noted.

Virtually all copper ore is beneficiated at the mine. Although some ores are sufficiently high grade for direct smelting and some oxide ores are treated directly by leaching, the average tenor of ores mined in the United States is less than 1 percent. Beneficiation, or ore dressing, comprises the two steps of comminution in which the ore is crushed and ground to liberate the individual mineral particles, and concentration by means of which the comminuted ore is mechanically separated into waste material or tailings and the copper concentrate. The concentrate, on the order of 30 percent copper, is delivered to the smelters by rail, barge, or conveyor belts.

Several plants are in operation which produce satisfactory matte without

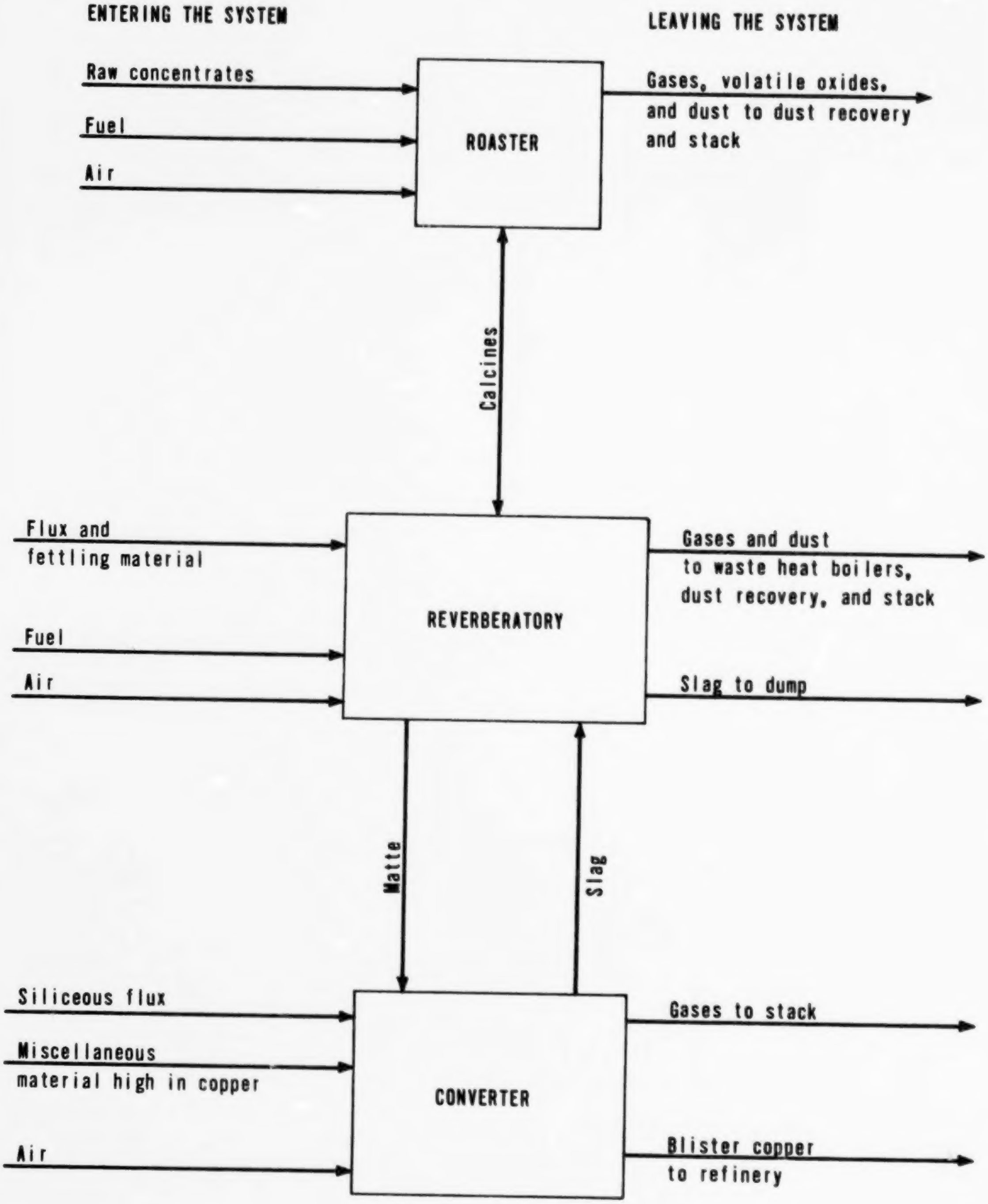

ENTERING THE SYSTEM
LEAVING THE SYSTEM
Raw concentrates
Fuel
Air
ROASTER
Gases, volatile oxides, and dust to dust recovery and stack
Calcines
Flux and fettling material
Fuel
Air
REVERBERATORY
Gases and dust to waste heat boilers, dust recovery, and stack
Slag to dump
Matte
Slag
Siliceous flux
Miscellaneous material high in copper
Air
CONVERTER
Gases to stack
Blister copper to refinery

FIGURE III-2 PRODUCTION OF BLISTER COPPER FROM SULFIDE CONCENTRATES

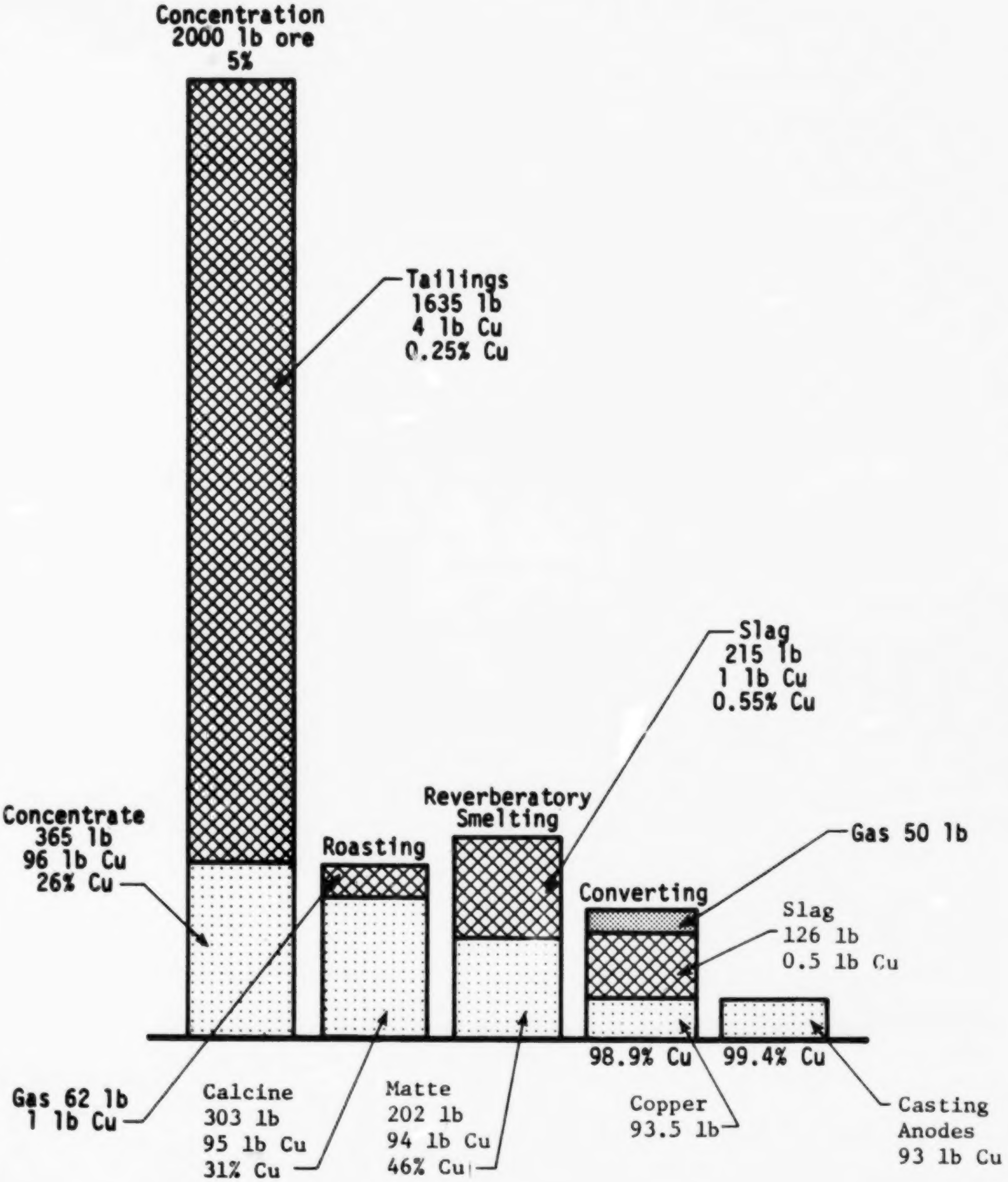


FIGURE III-3 CONCENTRATION AND SMELTING OF A COPPER ORE

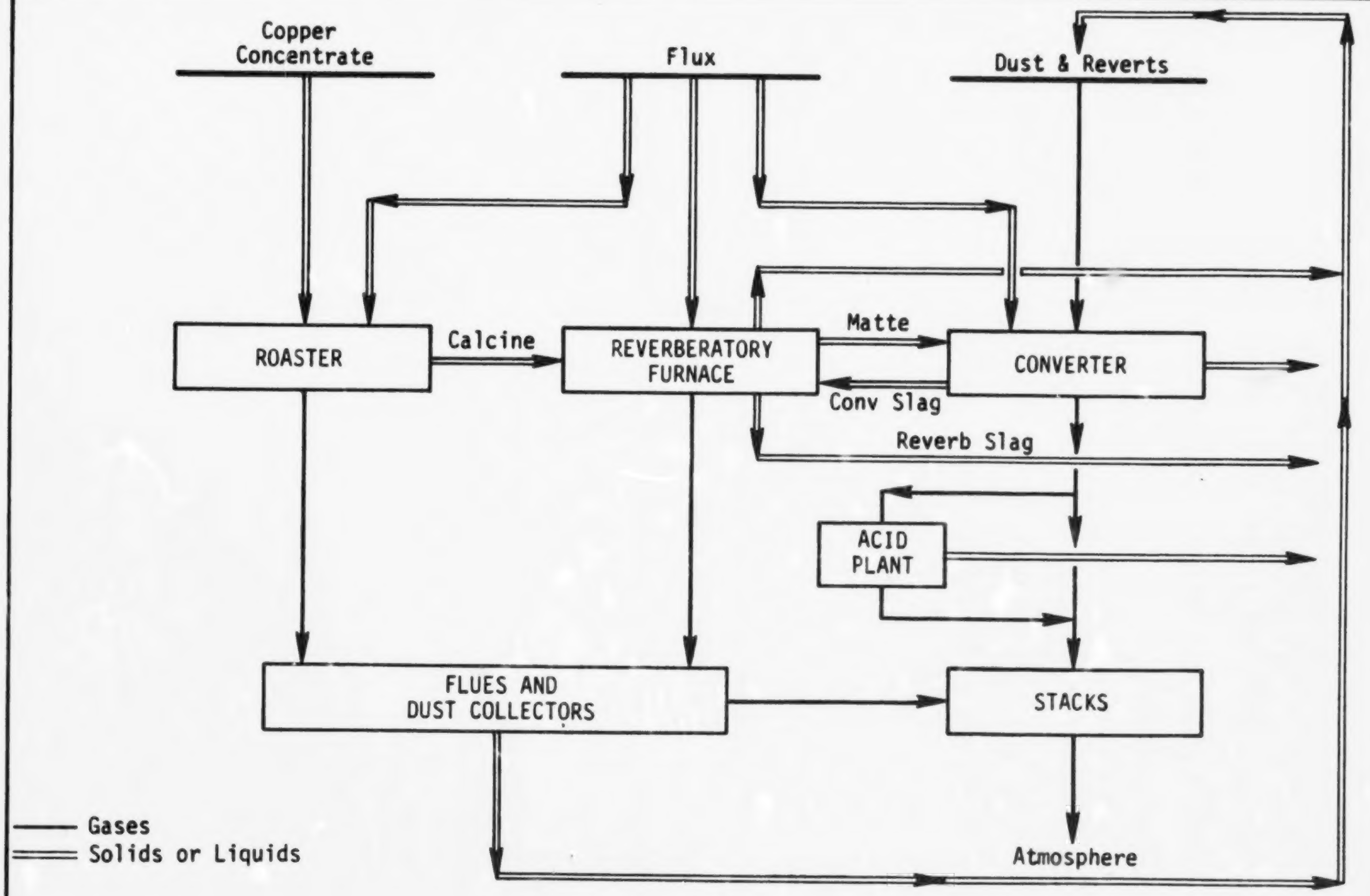

Copper Concentrate
Flux
Dust & Reverts
ROASTER
Calcine
REVERBERATORY FURNACE
Matte
Conv Slag
CONVERTER
Reverb Slag
ACID PLANT
FLUES AND DUST COLLECTORS
STACKS
Atmosphere
Gases
Solids or Liquids

FIGURE III-4 COPPER SMELTING EMISSION SOURCE DIAGRAM

roasting. In these cases, the concentrate may either be dried before smelting or the raw, moist concentrate may be fed to the reverberatory furnace. Figure III-5 provides an overall view of a copper plant and Figure III-6 shows typical cross section.

All smelters have waste heat boilers utilizing the waste heat from the reverberatory furnaces for power production and in some cases for air preheating and economizers.

Electrostatic precipitators were used extensively at copper smelters to prevent product loss, long before air pollution control regulations were promulgated. The dust from the converter may contain up to 45 percent copper. At some smelters an arsenious oxide by-product is recovered, primarily from the roaster and furnace gases.

Sulfuric acid plants may be considered add-on pollution control devices. Such plants are not integral parts of the smelter complex, and, consequently are not considered in this manual. However, as leaching of copper ores becomes more widespread, the on-site demand for sulfuric acid will increase and the production of sulfuric acid will become more attractive.

20. RECEIVING, STORING AND HANDLING OF RAW MATERIALS

The possible emission will be particulates.

20.1 Process Description

Copper ores are mined by underground methods and by open pit mining operations. From the mine, it is loaded onto railroad cars and shipped to the processing plant. The ore arrives at the plant in the form of small nuggets usually less than 2 inches in diameter. The ore is unloaded from the car and placed into storage bins for further processing. The ore is crushed, ground, screened, and then sent to the concentrator. From the concentrator the ore goes to roasters and then to the reverberatory smelting

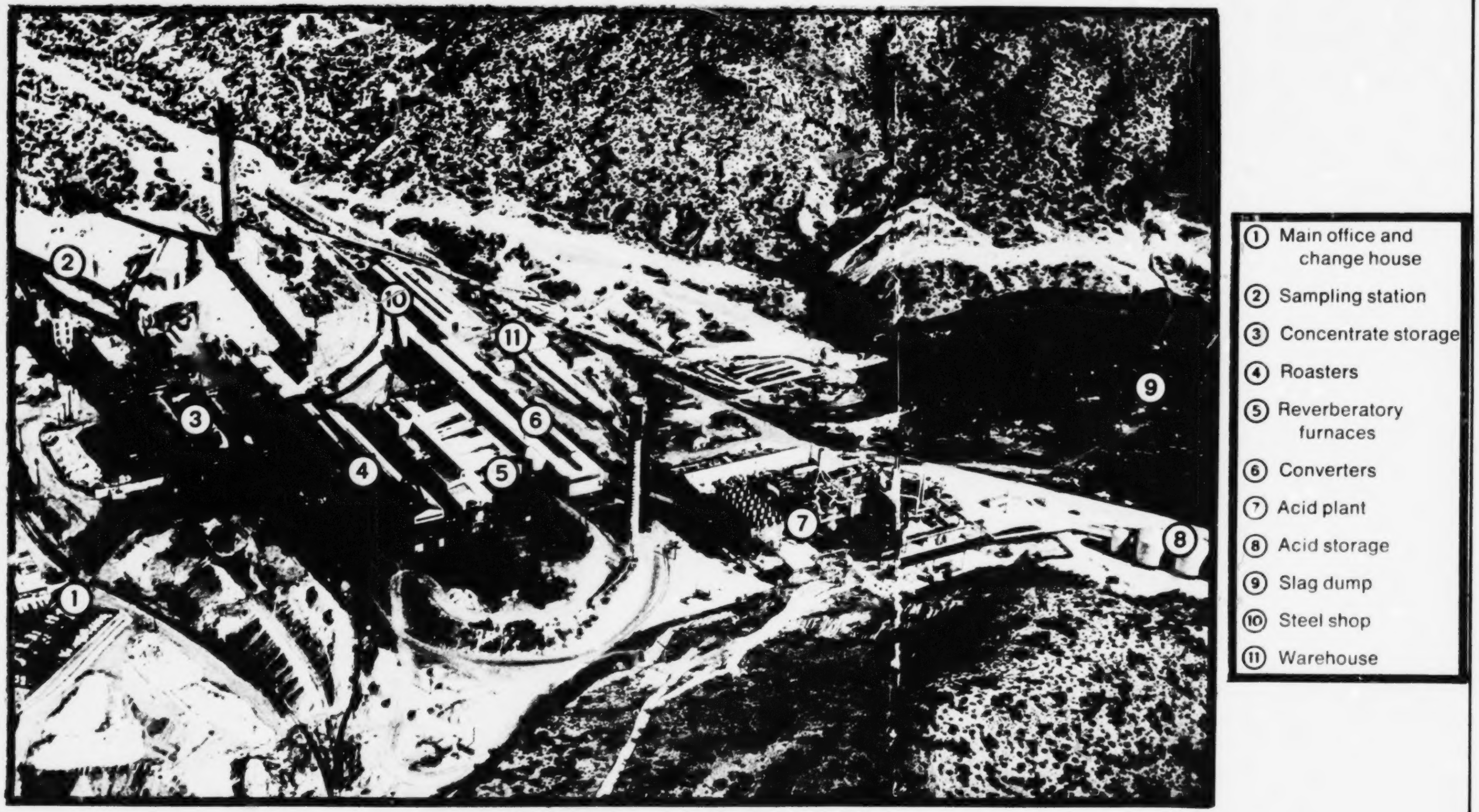

① Main office and change house
② Sampling station
③ Concentrate storage
④ Roasters
⑤ Reverberatory furnaces
⑥ Converters
⑦ Acid plant
⑧ Acid storage
⑨ Slag dump
⑩ Steel shop
⑪ Warehouse

FIGURE III-5 COPPER SMELTER

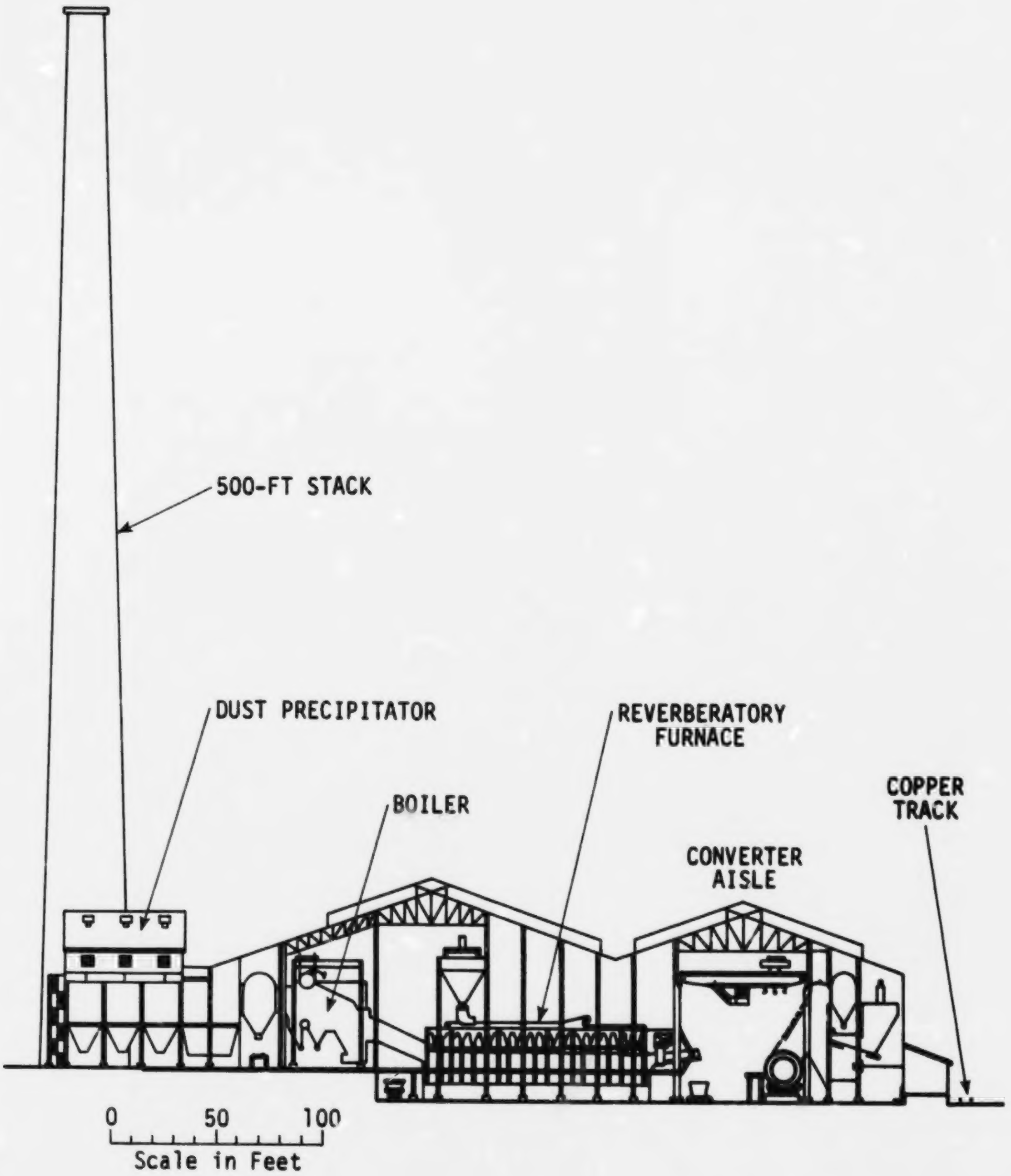

500-FT STACK
DUST PRECIPITATOR
BOILER
REVERBERATORY FURNACE
COPPER TRACK
CONVERTER AISLE
0
50
100
Scale in Feet

FIGURE III-6 SCHEMATIC CROSS-SECTION OF A SMELTER

furnaces. Once the copper leaves the reverberatory furnace, the matte is transferred to the converter. Finally, the copper goes through several refining stages before leaving the plant.

The major air pollution problem associated with the handling of the raw materials for a copper production plant occurs at the transfer points when the ore is first brought to the plant. Depending on operational practices at the plant, some of the ore may be stockpiled for future processing. The transfer of ore to and from storage, whether in fully enclosed containers or on open fields, has the potential of becoming a source of fugitive dust.

20.2 Process Control Operation

There is some plant motivation to reduce fugitive dust-type emissions from the transfer points of the material handling scheme at copper smelters. Dust losses represent product losses and in addition, dust at appropriate concentration can become a potential explosion hazard. For occupational safety-considerations then, it is undesirable for copper plant operators to have a dusty working environment. If any air pollution control schemes are used to remove the dust, they will likely consist of small baghouses. Water sprays are sometimes used to suppress dusting. Essentially, there are no operating variables that the enforcement official should be concerned with at this point that would affect air pollution emissions.

20.3 Enforcement Procedure

The enforcement official should inspect the material handling scheme at a copper smelter on a windy day. If any noticeable plumes exist on a windy day from any of the transfer points, storage hoppers, or stockpiles, it would indicate a deficiency of the plant's control procedure of reducing or minimizing fugitive-type dust. On the other hand, if no dust is noticeable on a windy day, it is safe to assume that the plant has adequate preventive measures for handling the raw ore.

The overview for the material handling scheme should be done on a hillside overlooking the coper smelting. At that point, the enforcement official should observe the precise sources of dust and identify them as being either from stacks or fugitive sources. The air pollution code which deals with materials handling, storage, and receiving of materials is one that applies to fugitive dust emissions. The enforcement official should subjectively observe the transfer points, storage hoppers, conveyors, and stockpiles. The enforcement official should fill out the Inspector's Worksheet for future reference.

The Inspector's Worksheet which follows may be useful for record keeping. Interpretation of these observations is heavily dependent upon the pertinent regulations governing fugitive dust emissions. Since many of these plants are located on a large plot of land, it may be important to discriminate between in-plant housekeeping problems and emissions which cross the property line.

21. CONCENTRATING

Fugitive dust regulations will govern.

21.1 Process Description

Concentration is a process used in many of these smelting operations to mechanically separate minerals in a raw-feed ore into the ore constituents. The concentration process is accomplished in a variety of means, based on differences in various mineral properties, such as, specific gravity, magnetic properties, and chemical properties. The flotation process

INSPECTORS WORKSHEET

FOR

RECEIVING, STORING AND HANDLING OF RAW MATERIALS

Plant Id.____

Date of this Inspection______________Date of last Inspection______________

Type of Plant____

Capacity of Plant____

Source Location	Type Material	Wind Direction Wind Speed mph	Plume Description	Preventive Measures
Sample Receiving hopper	Copper ore	SW/10	Brown	Baghouse used
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				

is now the most generally used concentration method. A weak slurry of ore is introduced to a vessel. Flotation agents cause the copper-bearing minerals to rise as a froth as the bath is agitated. The froth is skimmed and dried for use in the subsequent smelting operations. The flotation cell must have particles less than 0.3 mm with most being less than 0.1 mm. To accomplish this, wet grinding, crushing, screening, and classifying operations must take place before the ore is charged to the flotation cells.

The major source of air pollution emissions from the concentrator plant is the material handling of the raw ore to and from the storage bins. The ore usually arrives at the plant in railroad cars. The moisture content of the raw ore is about 3 percent. The ore is transported from the railroad car to the storage bin by belt haulage ways. Transfer points at the belt haulage ways are potential sources of air pollution emissions. These emissions can be reduced by water sprays since water will not interfere with the processing of the ore. No emissions from the flotation cell are of concern to the air pollution control engineer.

21.2 Process Control Operation

There is little process information of significance to the air pollution control engineer at the concentrator plant. Certain scales may be used to weigh the amount of ore processed through this building. The amount of chemicals used and the amount of water used for the flotation cells are not important for the enforcement official. The drying mechanism used to remove much of the water from the froth slurry consists of rotating drums which have virtually no particulate emissions.

21.3 Enforcement Procedure

The enforcement official should record the amount of material processed through the concentrator building. These records can be used for future comparisons to determine whether any increase of production occurs at this plant. These daily operating records are likely to be kept by plant officials as part of their overall monitoring of the plant operation.

The enforcement official should observe the material transport system and note if there are any dust plumes generated especially at the transfer points. Water sprays can be used as a dust suppressant for many of these material handling schemes. From outside the building, note whether any plume escapes through the roof monitors. Finally, record the moisture content of the concentrate leaving the process.

22. CONCENTRATE ROASTING

This is a major point of sulfur emissions in the copper smelting process. It is also a possible major source of particulate emissions if control equipment is not functioning properly. Individual plants may not have sulfur recovery units.

22.1 Process Description

Roasting is the pyrometallurgical process in which an ore or concentrate is heated in a specific atmosphere to a high temperature (but below the melting points of the constituents) in order to effect a desired chemical change and usually to eliminate, by volatilization, unwanted impurities. As distinguished from calcining, which is a chemical decomposition process, roasting is a chemical combination process. Although fundamentally different, the roasted product is called calcine.

In the roasting of sulfide copper ore or concentrates, the material is heated in an oxidizing atmosphere to eliminate a portion (but not all) of the sulfur as SO_2; to remove detrimental volatile impurities such as antimony, arsenic, and bismuth; and to convert a portion of the iron into iron oxides in which form it will be removed in the slag from the matte furnace. The amount of sulfur and iron to be oxidized in the roasting operation depends upon the desired quality of the charge to the reverberatory furnace. With a given concentrate to treat, the smelter personnel must decide how much sulfur, if any, to remove by roasting in order to put the reverberatory and converter operation in the best economic position.

The desired reduction in the sulfur content is normally effected in a roasting furnace of which there are two types: multiple-hearth and fluid bed. The two are similar in metallurgical principle and involve the following considerations:

1. Roasting is an oxidation of the copper and iron sulfides with oxygen in the air as the oxidizing agent. An adequate supply of air is necessary. Representative reactions would include, among others:

$$4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2$$

$$4CuFeS_2 + 13O_2 \longrightarrow 4CuO + 2Fe_2O_3 + 8SO_2$$

2. The principal combustion product is SO_2 which must be cleared from the roaster atmosphere to continue the reaction. At high SO_2 concentrations the reaction virtually ceases.
3. No part of the roaster charge nor the calcine becomes liquid; hence the reaction occurs only when particle surfaces are exposed, necessitating a finely milled concentrate charge.
4. Temperatures must be maintained high enough to ignite the sulfide charge and maintain combustion temperatures. Self roasting ores, i.e., at least 24 percent sulfides, release enough heat to maintain the proper temperature without added fuel.

22.1.1 Multiple Hearth Roasting Furnace

Figure 22.1 is a sectional drawing of a typical multiple hearth furnace. This older type roaster is gradually being replaced by the more modern fluid bed roaster.

The hearths are constructed of refractory brick with a slight arch. The external portion of the furnace is a brick-lined, steel shell with hinged doors and inspection plates at each level. The moist concentrate enters the roaster proper through an annular opening to the top-most or dryer hearth. Rabble arms, attached to the hollow central shaft, are rotated as the shaft turns and plow through the charge to continually expose fresh surfaces to the oxidizing air. The rabble blades are set at an angle and, in addition to stirring the material, move it alternately either to the center of the hearth or to the periphery where it falls to the next lower hearth. Finished calcine is discharged through holes on the circumference of the bottom hearth.

The air required for roasting is admitted through the central shaft and by means of valves the air supply to each hearth may be regulated. Roaster gases are drawn off through gas outlets located just below the drier hearth. A luted discharge from the dryer hearth to the top roasting hearth prevents escape of gas from the interior of the roaster.

Burners for fuel oil, gas, or pulverized coal are set in the side wall to preheat the roaster to combustion temperature upon start up and when the concentrate does not contain enough sulfur to be self-roasting.

Multiple hearth roaster off gases contain variable amounts of SO_2 because of the wide variation in concentrate constituents and desired matte quality. For low sulfur concentrates requiring continuous auxiliary fuel,

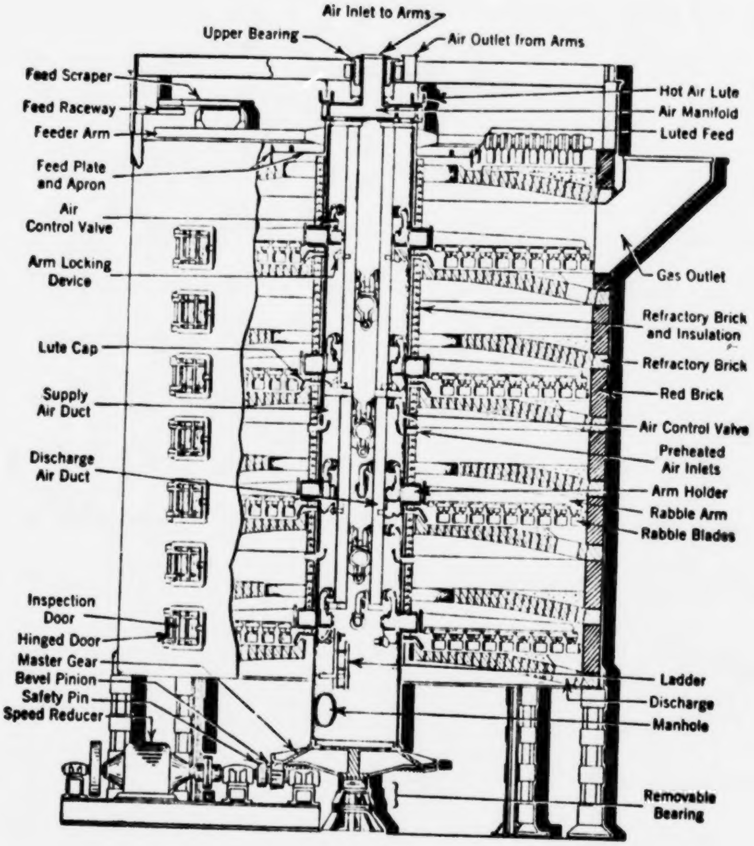

Air Inlet to Arms
Upper Bearing
Air Outlet from Arms
Feed Scraper
Feed Raceway
Feeder Arm
Feed Plate and Apron
Air Control Valve
Arm Locking Device
Lute Cap
Supply Air Duct
Discharge Air Duct
Inspection Door
Hinged Door
Master Gear
Bevel Pinion
Safety Pin
Speed Reducer
Hot Air Lute
Air Manifold
Luted Feed
Gas Outlet
Refractory Brick and Insulation
Refractory Brick
Red Brick
Air Control Valve
Preheated Air Inlets
Arm Holder
Rabble Arm
Rabble Blades
Ladder
Discharge
Manhole
Removable Bearing

FIGURE 22.1 MULTIPLE HEARTH ROASTER

values as low as 1 percent SO_2 may occur. On the other hand, values up to 10 percent may result from completely self-roasting concentrates. In general, the average would be in the range of 4 to 5 percent.

Particulate gas loadings are high with the countercurrent air flow, ranging from 3 to 6 percent of feed depending upon the size distribution of the concentrate. The flue dust may contain anything that was in the original concentrate charge and, if pulverized coal is used as the firing fuel, a certain amount of ash. Since the dust contains an average of about 7 percent copper, it is economically attractive to recover the dust for feed to the reverberatory or converter. Preliminary dust collection in a cyclone is followed by gas cooling and final dust collection in an electrostatic precipitator.

22.1.2 Fluid Bed Roasting Furnace

With the increased concern for sulfur dioxide air pollution control at smelters, there is a revival of interest in the roasting of copper concentrate in a manner which produces SO_2 rich gas. New installations are almost invariably fluid-bed roasters.

The fluid-bed roaster is similar in appearance to a multiple hearth roaster but does not include the intricate internal mechanical systems. Finely ground material (60 percent minus 200 mesh) passes over a drying hearth and through a chute and feeder into a ball-mill to break up agglomerates formed in drying, or is introduced as a slurry. The feed is continuously delivered into the combustion chamber. Roasting occurs as the sulfide particles are falling through the oxidizing air.

Combustion air from the windbox passes up through distribution plates at the bottom of the chamber into the combustion zone. Because of the large surface area of the finely ground material exposed to the air stream the residence time in the oxidizing atmosphere is short. The reaction is self-sustaining. Oil, gas, or pulverized coal burners are required only to preheat the roaster to combustion temperature.

Roaster gases are drawn off through flues at the top of the chamber and pass immediately to cyclone collectors, followed by cooling and final dust collection. As much as 85 percent of the feed is carried with the gas stream and, hence, the cyclones are an integral part of the roasting operation. Screw conveyors collect this finished calcine and that from the bottom of the combustion chamber for discharge into hoppers.

SO_2 concentrations are considerably higher than for multiple hearth roasters due to the lower total air volume. Average stack gas SO_2 concentration is about 12 percent with maximums near 18 percent.

22.2 Process Control Operation

For either type roaster there are three operating variables: feed rate, combustion air flow rate, and temperature. Day-to-day operation of the roaster will depend upon the chemical and physical characteristics of the feed concentrate, the quality of the calcine desired for the reverberatory furnaces, and whether or not the off gasses are being treated for sulfur removal. It would be expected that some variation in operation will occur at any one smelter and that large variations will occur between several smelters that have roasting operations. Typical operating ranges are given below:

	Multiple Hearth	Fluid Bed
Feed rate (tons/day)	150 to 800	700 to 1,500
Air Flow Rate (103 scfm)	100 to 130	6 to 25
Temperature (^{o}F)	1,200 to 1,800	1,200 to 1,750

For economic reasons the three operating variables are carefully controlled. The furnace operator can regulate rate-of-feed, air supply, and temperature in such a way as to obtain the maximum efficiency for the material being treated. Hourly values are usually recorded.

22.3 Enforcement Procedure

The objectives of copper concentrate roasting operation inspections are to establish compliance with the sulfur dioxide and particulate emission regulations. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both roaster and roaster emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels, roaster feed weight rates, roaster and roaster emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

All copper roasters will have a control booth near the roaster for careful monitoring. The enforcement official should have little difficulty in assessing the current operating status of the roaster by observing the many recorders, gauges, and log sheets which are normally kept for the roaster.

Of primary importance for the enforcement of air pollution emission regulations is the process weight rate and the sulfur content. With the mass rate and sulfur content of the feed and calcine, a sulfur mass balance can be calculated. From this, SO_2 emissions can be computed. It should be pointed out that many state regulations restrict sulfur emissions from the entire copper smelter and not just the copper roaster. For determining compliance with the regulations, sulfur emissions from each operation must be summed, then compared.

Many copper roasters have a sulfuric acid plant to treat exhaust gases from the roaster. These plants monitor SO_2 gases continuously. The enforcement official should note the flow and concentration of the acid plant inlet and outlet gas for subsequent inspections. There should be little deviation ($\pm$ 20) from visit to visit because of the fixed design of acid facilities.

There is little that can be noted on instrument panels regarding the amount of particulates emitted to the atmosphere. Some plants will have a smoke density meter which may be used to determine relative particulate emissions from one visit to another. The enforcement official should note the pressure drop, spark rate, flow rate, and the operational parameters of the air pollution control devices.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plume and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine points of origin and require corrective action.

The enforcement official should subjectively analyze the appearance of the copper roaster and note any leaks, SO_2 odors, condition of the duct, etc. Finally, some attention should be given to the dust emission from the material handling of the feed ores and calcine to and from the roasting machine.

23. CONCENTRATE SMELTING

This is a major potential particulate emission and moderate sulfur emission process. Particulate emissions are mainly a function of the adequacy of the control system.

23.1 Process Description

Smelting is the pyrometallurgical process in which solid material is melted and subjected to certain chemical changes. In the smelting of copper, hot calcines from the roaster or raw unroasted concentrate with siliceous or limestone flux are melted in a reverberatory furnace. Converter slag, collected dust, ladle skulls, refinery slag, oxide ores, and any other material rich in copper may be added to the furnace charge. The copper and iron which are present in the charge combine with sulfur to form cuprous sulfide, Cu_2S, and ferrous sulfide, FeS. For example, covellite and pyrite, upon being heated to a high temperature, will decompose according to the equations:

$$2\ CuS \longrightarrow Cu_2S + S$$

$$FeS_2 \longrightarrow FeS + S,$$

and the oxides according to:

$$2\ Cu_2O + 3S \longrightarrow 2\ Cu_2S + SO_2$$

$$2\ FeO + 3S \longrightarrow 2\ FeS + SO_2.$$

The more complex associations of copper, iron and sulfur break down in a similar way:

$$2\,CuFeS_2 \longrightarrow Cu_2S + 2FeS + S$$

The net result is the formation of the two stable compounds and the volatilization of some sulfur which is immediately oxidized to SO_2. The two sulfides are miscible in all proportions in the liquid state, and the mixture, whether liquid or solid, is known as copper matte. In practice, the matte contains about 95 percent copper and iron sulfides, with sulfides of various other metals and arsenic, antimony, selenium, and tellurium accounting for the remainder. The precious metals remain dissolved in the matte and are recovered later in the refining process.

The amount of matte produced as a percentage of the total charge is called the matte fall; the percent of copper is the grade of the matte. Bluish-purple mattes containing 40-45 percent are best for efficient converter operation. Low grade matte, a dull bronze in color and containing 20-40 percent copper, makes the converting process economically unattractive. High grade matte, a whitish color, containing more than 70 percent copper, although economically converted, requires excessive roasting, results in high copper loss, as well as insufficient matte to collect the precious metals, and difficulty in converter operation.

The purpose of the smelting process is the separation of the gangue minerals in the charge from the matte. The material which contains these minerals is called slag. Essentially slags are a molten solution of complex ferrous silicates in which are dissolved smaller amounts of other basic oxides (Al_2O_3, CaO, and MgO). The slag also contains a small amount of copper and sulfur.

The fluxes used to form the slag are mixed to a composition and quantity to combine with all the gangue present in the copper-rich material and to produce a slag of suitable properties and volume. Although in some cases a charge may be self-fluxing, it is generally necessary to add either siliceous materials or limestone according to the nature of the deficiency. Silica is often added in the form of siliceous copper ores. The iron-rich slag from the converters is almost invariably charged into the reverberatory furnaces and this material also exerts a fluxing action by providing iron oxide, and is thus useful in counteracting any excessive slag acidity.

Reverberatory furnaces are long room-like structures from 80 to 130 feet long and 10 to 35 feet wide. Figure 23.1 is a sketch of such a furnace. Capacities range from 50 to 1,500 tons of charge per day. Oil, natural gas, or pulverized coal is burned in a separate compartment from which the flame and hot gases pass over the molten mass. Heating of the charge is principally accomplished by radiation from the roof and side walls rather than by direct contact with the hot gases. There is little reaction between the gases in the furnace atmosphere and the material on the hearth. It is possible to get some oxidation of the charge by using a large excess of air for combustion, but this is uneconomical and is seldom practiced. The principal chemical reactions that take place in the reverberatory furnace are between the various constituents of the charge to form the matte and the slag.

The concentrates, hot calcines and fluxes are brought in cars on tracks or on conveyor belts above the reverberatory furnace and charged to hoppers. In some of the latest construction, the roaster is placed directly above the furnaces where the roasters discharge directly into the charge hoppers, flow being gate-controlled.

The contents of the hoppers are charged above and along the sides of the furnace forming charge piles on each side of the central molten bath

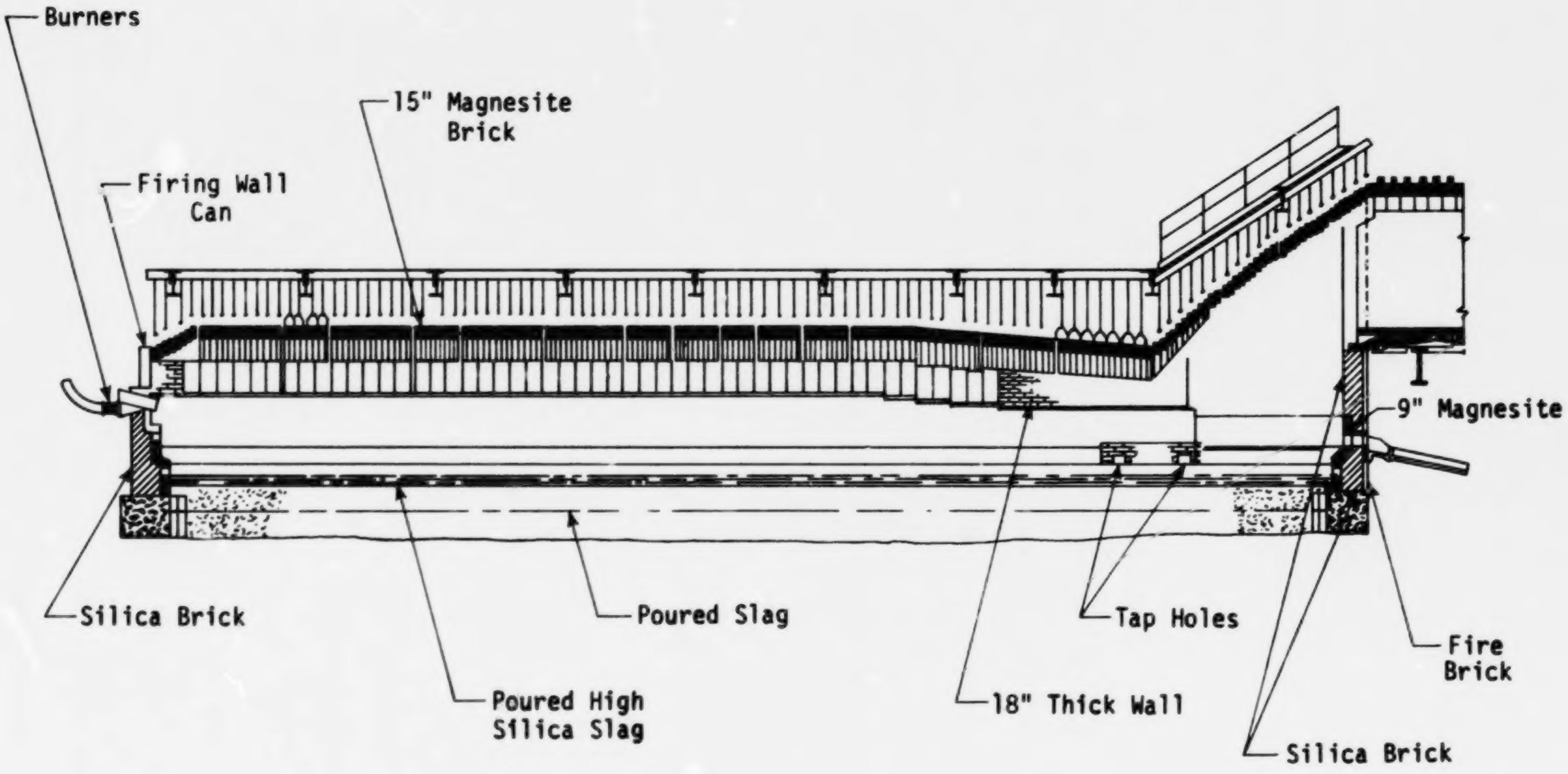

Burners
15" Magnesite Brick
Firing Wall Can
9" Magnesite
Silica Brick
Poured Slag
Tap Holes
Fire Brick
Poured High Silica Slag
18" Thick Wall
Silica Brick

FIGURE 23.1 SECTION OF REVERBERATORY FURNACE

of matte and slag. Water-cooled gun feeders allow the charge to flow over the surface with minimum disturbance. At one plant using raw concentrate the moist charge is introduced by means of high-speed belt slinging machines which deliver a ribbon-like thin layer over the surface of the bath.

As new charge is added and fuses into the bath, the volume of molten matte and slag increases. The depth of the bath at the firing end may be three feet and the slag, because of its lower density, floats on top and is usually allowed to overflow continuously from the skimming door or slag notch located near the exhaust end of the furnace. Launders lead to slag cars which then carry the slag to the slag pit. The matte is tapped intermittently from tap holes near the bottom toward the firing end of the furnace and conveyed in a molten condition to the converter plant.

The furnace is fired by high capacity burners located in one end of the furnace. In some cases, auxiliary burners are set in the side walls near the back. Rapid and complete mixing of air and fuel is necessary in order to liberate the maximum amount of heat close to the burners where most of the heat is required. Secondary air is drawn in around the burner to provide about 5 percent excess air. Waste heat boilers are almost universally used. The boilers are constructed without baffles to prevent draft loss and to maintain negative pressure which prevents gas escape. Up to 40 percent of the flue gas sensible heat is recovered in the waste heat boiler and, in some cases, an additional 10 percent may be recovered in combustion gas preheaters. These heat recovery systems not only reduce overall fuel requirements but also serve to cool the gases before entering the primary dust recovery system.

Combustion gases will contain from 15 to 30 percent of the sulfur in the original charge depending primarily upon whether or not the concentrate was roasted, but because of the high volume of combustion air, SO_2 concentrations are low, varying from 0.5 percent to 3.5 percent. These lean SO_2 mixtures, unlike off gases from the roasters and converters, are not economically utilized as feed for sulfuric acid plants or other sulfur recovery methods.

Particulate loading in the combustion gas will vary from 2 to 5 gr/scf which, for a large furnace at maximum production rate, would produce 80 tons of particulates per day. Dusting within the furnace is greatly reduced where moist concentrate is used as the charge, and where furnace feeding operations are carefully controlled. Pulverized coal will result in a certain amount of ash contained in the flue gases.

Heavy particulate matter settles out below the waste heat boilers or in the balloon flues leading to the primary dust collection system, from which it is collected and returned to the system to recover copper. Final dust collection is performed by an electrostatic precipitator. Table 23.1 lists the operating parameters of the reverberatory furnaces in the United States.

23.2 Process Control Operation

There are three operating variables for a reverberatory furnace: (1) feed rate, (2) combustion air flow rate, and (3) furnace temperature. Although the furnace operation is continuous, the through-put rate must be varied to match the availability of converter capacity. The matte is transferred to the converters in the molten state in ladles; hence, the matte formation and, consequently, the feed rate is adjusted to meet converter requirements. Further, on occasion, an upset may occur upstream in the system and limit the availability of furnace charge.

The feed rate, in turn, determines the air flow rate and fuel feed rate. If converter capacity has been reduced through breakdown or other cause, furnace charge is reduced and the fuel feed rate and combustion air are reduced to that required only to maintain the correct temperature required for the molten bath. This temperature may vary to a limited degree, but it is economically important that it be carefully controlled. At the firing end of the furnace, a temperature of around 2,800°F is required to maintain the desired fluidity of the matte. Depending upon furnace length and charge rate, the exhaust end temperature must be sufficiently high to permit free-running matte and slag with efficient separation. Temperatures higher than required are wasteful of fuel. Exhaust-end temperatures are around 2,000°F.

Listed below are typical operating ranges for reverberatory furnaces operating at designed capacity.

Feed rate (tons/day)	400 to 1,500
Air flow rate (10^3 scfm)	26 to 155
Temperature (°F)	2,000 to 2,800

Exhaust gas temperatures from the furnace average near 2,600°F. Gas temperatures following the waste heat boilers average 700°F with further cooling by dilution air to 600°F before the precipitator.

In the past it was necessary to shut down the reverberatory furnace periodically for repair of the refractory material. Since the adoption of hot patching methods, furnace campaigns have been extended almost indefinitely and furnace shut downs are rare. Upset conditions may occur in feed mechanisms or burner operation, but the result of such upsets is merely to reduce the through-put rate.

TABLE 23.1

REVERBERATORY SMELTING DATA

	A. S. & R. No. 1	A. S. & R. No. 2	A. S. & R. No. 3	A. S. & R. No. 4A	A. S. & R. No. 4B	Anaconda Anaconda, Mont.	Kennecott McGill, Nev.
→ Furnace Dimensions							
Length, Inside	117 ft.	119 ft.	104 ft.	118 ft.	115 ft.	133 ft. 7 in.	131 ft. 6 in.
Width, Inside Firing End	26 ft. 6 in.	25 ft.	27 ft.	23 ft.	24 ft.	22 ft.	28 ft. 10 in.
Flue End	19 ft. 6 in.	19 ft. 6 in.	15 ft. 9 in.	18 ft.	16 ft.	19 ft. 6 in.	18 ft. 9 in.
Height, Inside Firing End	4 ft. 9 in. Skim line to center of arch	10 ft. 6 in.	7 ft. 6 in. to skew back 10 ft. 4 in. top of arch	9 ft. 7 in. from floor plate	12 ft. 9 in. from floor plate	10 ft. 7 in.	8 ft. to top of skimming bay
Flue End	4 ft. 9 in. Skim line to center of arch	9 ft. 6 in.	8 ft. 10 in. to skew back 9 ft. 8 in. top of arch	9 ft. 7 in. from floor plate	8 ft. 10 in. from floor plate	8 ft. 3 in.	6 ft. 6 in. to top of skimming bay
Side Wall Thickness at Slag Line	6 in. copper water jacket	27 in. smelting zone 18 in. settling zone	18 in. magnesite 24 in. silica	15 in.	15 in.	24 in. inside water jackets	5 ft. 8-3/4 in.
Side Wall Thickness above Slag Line	12 in.	27 in. smelting zone 18 in. settling zone	15 in.	15 in.	15 in.	34 in.	20 in. just below skewback
Roof Thickness	20 in.	20 in.	20 in.	20 in.	9 in. firing zone 20 in. bay	27 in. + 12 in. rib in smelting zone	20 in.
Area Gas Uptake	104 sq. ft.	97 sq. ft.	122 sq. ft.	78 sq. ft.	112 sq. ft.	140 sq. ft.	114 sq. ft.
→ Refractory Data							
Kind of Brick, Roof	Silica	Silica	Silica Suspended fire brick in uptake	Silica	Silica Suspended fire brick in smelting zone	Silica	Silica except fire brick at firing end
Side Walls	Standard fire brick or Reclaimed silica brick	Silica	Silica	Silica above charge Magnesite below	Silica above charge Magnesite below	Silica	Silica see footnote *
Hearth Material	Slag	8 ft. slag 2 ft. magnetite-matte	20 in. fused magnesite on poured slag	Slag	Slag	Silica	Silica
Type and Location of Water Cooling	Copper water jackets along 2/3 of walls from firing end.	Pipe coils in copper at burners, slag launder, gun feed, side walls, near front, skim bay.	Copper water jackets in bridge wall above burners. Cast iron jackets over burners.	Copper water jacket first 36 ft. at slag line.	Copper water jacket first 36 ft. at slag line.	Cast iron jackets with embedded steel pipe all around furnace. Jackets 5 ft. high and 11 in. below floor line.	None
→ Firing Data							
Kind of Fuel	Natural gas	Natural gas	Natural gas	Oil	Oil	Natural gas	Bituminous coal
Number, Type and Size of Burners	7 multiple jet inspirating burners	8 multiple jet 9/64 in. orifice, 1-5/8 venturi	7 multiple jet	6 modified 3 in. steptoe burners	8 - 6 in. Hauck low pressure No. 784	6 DFC modified No. 10052	A - seven 8 in. pipe B - seven 9 in. pipe C - seven 10 in. pipe
Amount of Fuel per Day	2,400,000 cu. ft.	3,600,000 cu. ft. @ 60°F.	1,623,000 cu. ft.	16,422 gal.	19,320 gal.	3,057 000 cu. ft.	A - 146 tons B - 175 tons C - 207 tons
Fuel per Ton of Solid Charge	3,800 M. B.t.u.	3,700 cu. ft.	3,180 cu. ft.	22.8 gal.	23.4 gal.	4,149 cu. ft.	A - 29 per cent B - 22 per cent C - 19.7 per cent
Fuel per Ton of Total Charge	3,300 M. B.t.u.	2,600 cu. ft.	2,580 cu. ft.	16.9 gal.	17.6 gal.	3,184 cu. ft.	--
Temp. Exit Gases	650° F. leaving waste heat boilers	2300° F.	2100° F.	2400° F.	2400° F.	2200° F.	A - 2220° F. B - 2190° F. C - 2150° F.
Per Cent Calories Recovered in Steam	40	38	35-40	42.8	42.8	34	

Is Automatic Draft Control Used?	Yes	No	Yes	No	Yes	Yes	No
Type Waste Heat Boilers	400 lb. Stirling	Erie City 3 Drum	Keeler 2 Drum	1 - 500 H.P. Stirling 1 - 700 H.P. Puget Sound	2 - 1000 H.P. Erie City	Stirling Class A and 2-1/2. Two boilers used in tandem on each furnace	Three Stirling 779 H.P. each
Charge Data per 24 Hours							
Wt. Hot Calcine	650 tons	900 tons	490 tons	730 tons	812 tons	652 tons	None
Wt. Raw Concentrate	None	900 tons including copper precipitates	None	None	None	31.5	A - 403 tons B - 695 tons C - 948 tons
Av. Moisture in Raw Conc. Pct.	--	11	--	--	--	3.7	8.5
Wt. Crushed Ore	240 tons	80 tons	None	None	None	None direct	A - None B - 9 tons C - None
Wt. Flue Dust	13 tons	50 tons	10 tons	12 tons	13 tons	21.95	A - 19 tons B - 23 tons C - 27 tons
Wt. and Nature of Fettling Material	20 tons slag and matte skulls at bridge wall	None	10 tons slag and matte shells etc.	None	None	2.83 siliceous ore at burner wall	A - 4 tons siliceous flux B - 7 tons siliceous flux C - 25 tons siliceous flux
Wt. and Nature of Flux	75 tons siliceous ore, 75 tons 3/8 in. limerock	60 tons lime sand 47 pct. CaO 7 SiO_2	170 tons mixed with concentrates before roasting	None	None	65 tons limerock 73 tons siliceous ore in roaster	A - 49 tons silica 26 limerock B - 18 tons silica 32 limerock C - 26 tons silica 24 limerock
Wt. Liquid Converter Slag	460 tons	375 tons	120 tons	232 tons	274 tons	223.5 tons	A - 243 tons B - 437 tons C - 687 tons
Wt. and Nature of Other Material	25 tons foreign matte and slag	25 tons skulls, barrings, etc.	None	None	None	28.9 tons secondaries	A - 3 tons copper precipitate B - 8 tons copper precipitate C - None
Where and How Is Furnace Charged	Wagstaff gun feed at side walls	Wagstaff gun feed at side walls	Wagstaff gun feed at side walls	Wagstaff gun feed at side walls	Wagstaff gun feed at side walls	Pipes at sides of roof	Vibrator conveyors 80 ft. along sidewalls
Product Data							
Depth Molten Charge	50 in.	42 in.	27 in. matte 12 in. slag	46 in.	48 in.	44 in.	40 in.
Tons Slag per 24 Hour	550	625	367	450	510	478	A - 356 B - 557 C - 798
Method Slag Disposal	Dumped hot	Dumped hot	Dumped hot	Dumped hot or granulated and sold	Dumped hot or granulated and sold	Granulated	Granulated
Tons Matte per 24 Hour	400 tons	625 tons	229 tons	392 tons	430 tons	383 tons	A - 329 B - 383 C - 822
Vol. Gas per 24 Hour Stand. Cond.	30,200,000 cu. ft.	33,000,000 cu. ft.	17,853,000 cu. ft.	38,155,700 cu. ft.	44,841,600 cu. ft.	33,012,825 cu. ft.	A - 80,250,000 cu. ft. B - 95,200,000 cu. ft. C - 112,800,000 cu. ft.
Per Cent Cu in Matte	38	43.5	39.4	39.9	39.7	40.7	A - 33.5 B - 33.3 C - 32.3

* Magnesite Crucible Fire Brick used above burner front base. Magnesite between tap holes and 3 ft. 6 in. on each side.

A - Supplying one converter.
B - Supplying two converters.
C - Supplying three converters.

TABLE 23.1

REVERBERATORY SMELTING DATA (Continued)

	Kennecott Hurley, N. M.	Magma Superior, Ariz.	Noranda Noranda, Que.	International Inspiration, Ariz.	International Nickel Copper Cliff, Ont.	Phelps Dodge Douglas, Ariz., No. 9	Phelps Douglas Morenci, Ariz.	Phelps Dodge Ajo Ariz.
Furnace Dimensions								
Length, Inside	121 Ft. 10 in.	98 ft.	110 ft.	120 ft.	110 ft.	104 ft. 9 in.	103 ft. 6 in.	100 ft.
Width, Inside Firing End	28 ft. 8 in.	22 ft.	30 ft. 6 in.	25 ft.	24 ft.	27 ft. 1 in.	27 ft.	30 ft.
Flue End	28 ft. 8 in.	10 ft.	26 ft.	25 ft.	12 ft.	24 ft. 6 in.	27 ft.	30 ft.
Height, Inside Firing End	11 ft. 5 in.	8 ft.	6 ft. above slag level	9 ft. 8 in.	10 ft.	10 ft. 7 in.	12 ft. 1-3/4 in.	11 ft. 6 in.
Flue End	11 ft. 5 in.	8 ft.	4 ft. above slag level	8 ft.	8 ft. 6 in.	10 ft. 7 in.	12 ft. 1-3/4 in.	11 ft. 6 in.
Side Wall Thickness at Slag Line	4 ft. 3 in.	30 in.	25-1/2 in.	30 in.	2 ft. 3 in.	Jackets	21 in.	Jackets
Side Wall Thickness above Slag Line	20 in.	18 in.	18-1/2 in.	30 in.	22-1/2 in.	18 in.	21 in. and 12 in.	18 in.
Roof Thickness	20 in.	20 in.	12 in. (Suspended roof)	20 in.	12 in.	20 in.	20 in.	20 in. + 15 in. Ribs
Area Gas Uptake	146 sq. ft.	98 sq. ft.	100 sq. ft.	82 sq. ft.	130 sq. ft.	157 sq. ft.	184 sq. ft.	150 sq. ft.
Refractory Data								
Kind of Brick, Roof	Silica	Silica	Magnesite	Silica	Brucite tile in cans Chemically bonded	Silica	Silica	Silica
Side Walls	Silica	Silica except magnesite at tap hole	Magnesite	Silica. Band of chrome & magnesite at matte line near front end	Base: magnesite inside fire brick outside. Top section: refractory mix in cans. 42 in. high, 18 in. wide, 8 in. thick.	Tamped periclase inside. Silica outside	Silica in charging zone. Magnesite beyond	Tamped periclase inside. Silica outside
Hearth Material	Crushed Quartzite slag cover	Silica	Silica	Tamped silica on cast slag	Poured slag	60 ft. chrome 43 ft. magnesite	Silica	Magnetite
Type and Location of Water Cooling	None	None	Copper water jackets at firing wall, uptake, skimming wall.	None	Burners and slag launders	20 in. water jackets on sides. Top and skim plates. Charge guns.	None	20 in. cast copper water jackets on sides. Tap and skim plates. Converter slag ports.
Firing Data								
Kind of Fuel	Natural gas	Natural gas	Pulverized coal	Natural gas	Pulverized coal	Natural gas	Natural gas	Natural gas
Number, Type and Size of Burners	8 multiple jet 84 jets per burner	Four surface combustion type	Four 16 x 4 in.	12 - 8 inch injector type at 60-70 lb.	4-burners 4-1/2 by 18 inch nozzle. Water cooled copper tip	5 - 8 in. injector type	6 - 8 in. injector type Single jet.	Leahy burners. 700 small jets. Low pressure air.
Amount of Fuel per Day	5,056,000	2,400,000	138 tons	3-4 million cu. ft.	150 tons	Capacity 4 billion B.t.u.	Capacity 4.5 billion B.t.u.	Capacity 5 billion B.t.u.
Fuel per Ton of Solid Charge	5,998	6,000	9.7 pct. = 194 lb.	5.5-6.0 million B.t.u.	0.21 ton	3.3 million B.t.u. when smelting 1100 tons per day	6.0-6.5 million B.t.u.	Designed for 5 million B.t.u. per dry ton wet charge
Fuel per Ton of Total Charge	--	--	--	3.8-4.2 million B.t.u.	0.13 ton	--	--	--
Temp. Exit Gases	2408°F	2200°F	2200-2300°F	2300°F	2250°F	--	500-600°F. from boilers	--
Per Cent Calories Recovered in Steam	51.54	38	30-35	45	--	--	±50	--

Is Automatic Draft Control Used?	No	No	No	No	--	--	--	--
Type Waste Heat Boilers	Stirling, three pass and one pass.	Erie City 2 drum	Stirling two per furnace	Stirling	--	Two Stirling with water walls. Each 32,600 lb. steam per day	Stirling. Each with 11,430 sq. ft. heating surface	Two Drum type rating 90,000 lb. steam per day
→ Charge Data per 24 Hours								
Wt. Hot Calcine	None	None	1,395 tons	None	--	Variable	None	None
Wt. Raw Concentrate	689 tons (dry)	300 tons	None	480 tons	660 tons	None	Variable. Bedded with fluxes, crushed reverts and flue dust before charging	Variable. Cold moist chalcopyrite concentrate
Av. Moisture in Raw Conc. Pct.	8.74	11.8	--	12 in total solid charge	8	--	9-11	--
Wt. Crushed Ore	None	18 tons	10 tons	None	None	Some used	--	--
Wt. Flue Dust	9 tons	1 to 2 tons	21 tons	3/4 ton average	None	Some used	--	--
Wt. and Nature of Fettling Material	30 tons mine ore 70 pct. SiO_2	80 tons (27 pct. ore, 6 pct. limerock, 67 pct. converter cleanings	--	3/4 ton at bridge wall	--	--	--	--
Wt. and Nature of Flux	38 tons limerock	--	3-5 tons siliceous material	Converter secondaries 6 tons, limerock 6 tons	35 tons sand	--	--	--
Wt. Liquid Converter Slag	449 tons	175 tons	± 600 tons	250 tons	448 tons	--	--	--
Wt. and Nature of Other Material	77 tons copper precipitates	None	1 ton	43 tons cement copper. 10 tons miscellaneous	8 tons scrap	--	--	--
Where and How Is Furnace Charged	Vibrator conveyors 70 ft. along sidewalls	Pipes at sides of roof	Pipes at side of roof to 60 ft. from burner	10 in. pipes at sides of roof. Drag line conveyor	Pipes at sides of roof	Wagstaff guns at sides	Pipes through sides of roof.	Portable high speed belt type slinging machines through holes in sides
→ Product Data								
Depth Molten Charge	33 in.	24 in.	37-38 in.	38 in.	34-38 in.	37 in.	38 in.	37 in.
Tons Slag per 24 Hours	539	250	1350	325	480	--	--	--
Method Slag Disposal	Dumped hot	Dumped hot	Dumped hot	Dumped hot	Dumped hot	--	--	--
Tons Matte per 24 Hours	671	2404	± 500 tons	480 tons	500	--	--	--
Vol. Gas per 24 Hour Stand. Cond.	83,800,000 cu. ft.	20,000 cu. ft. per min.	27,000 cu. ft. per min.	52,000,000 cu. ft.	43,000,000 cu. ft.	--	--	--
Per Cent Cu in Matte	34.85	34.5	34.3	44	38	--	--	--

* Magnesite Crucible Fire Brick used above burner front base. Magnesite between tap holes and 2 ft, 8 in. on each side.

A - Supplying one converter.
B - Supplying two converters.
C - Supplying three converters.

While the major source of particulate and sulfur dioxide emissions is the furnace stack, there are three other sources. Dust can be generated during loading and unloading of charging equipment. The slag launder and handling equipment are minor sources of sulfur dioxide. The matte launder and transfer ladle are another source of sulfur dioxide and particulates.

23.3 Enforcement Procedure

The objective of copper smelting operation inspection is to establish compliance with the sulfur dioxide and particulate emission regulations. In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both furnace and emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to plant inspection. Production levels, roaster feed weight rates, roaster and roaster emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

The furnaces will have a control booth nearby for careful monitoring. The enforcement official should have little difficulty assessing the current operating status of the furnace by observing the many recorders, gauges and log sheets which are normally kept.

Of primary importance for the enforcement of the air pollution emission regulations is the process weight rate and the sulfur content. With the mass rate and sulfur content of the feed, slag and matte, a sulfur mass balance can be calculated. From this, SO_2 emissions can be computed. Compare the computed emissions with allowable levels in the regulations. If required, take appropriate action.

It should be pointed out that many state regulations restrict sulfur emissions from the entire smelter and not separate processes. For determining compliance with the regulations, sulfur emissions from each operation must be summed, then compared.

There is little that can be noted on instrument panels regarding the amount of particulates emitted to the atmosphere. Some plants will have a smoke density meter which may be used to determine relative particulate emissions from one visit to another. The enforcement official should note the pressure drop, spark rate, and flow rate and operational parameters of the air pollution control devices.

The enforcement official should subjectively analyze the appearance of the roaster and note any leaks, SO_2 odors, condition of the duct, etc. Finally, some attention should be given to the dust emission from the material handling of the feed to the furnace. The enforcement official should inspect the dust handling system below the boilers and the flues and also trace out and inspect the balloon flues leading to the final dust collection system.

Two sources of effluent at the reverberatory furnace occur at the tap hole and the slag notch. Matte is drawn off intermittently into matte pots resulting in a rather significant source of smoke and dust which, if not collected, will be emitted through the roof monitors. Matte pots generally have ventilating hoods which collect the emissions and vent to ducting system.

No control is attempted for the slag skimming operation. The launders usually lead to slag cars outside the building. This and the continuous nature of the skimming process results in low mass emission rates and rapid dilution of the effluent.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plume and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust. If noted, determine point(s) of origin and require corrective action.

24. CONVERTING

This is the principal source of sulfur emissions in the copper smelting process. Individual plants may have recovery units. It may be a major source of particulate emissions, depending on the adequacy of the control equipment.

24.1 Process Description

Converting is the final pyrometallurgical process in the production of blister copper ready for refining. The process consists essentially in blowing air through the molten matte from the reverberatory furnace. The ferrous sulfide is oxidized to ferrous oxide and slagged off and the copper sulfide is oxidized to blister copper. Sulfur from both reactions goes off in the flue gases as sulfur dioxide.

Two types of converters are used:

1. The upright or Great Falls converter ,
2. The horizontal or Pierce-Smith converter.

The operation is similar with both. The general procedure is directed into two stages: the slag-forming blow and the copper blow.

About 20 tons* of molten matte at about 1,100°C are charged together with about 5 tons* of siliceous flux, either relatively pure quartz or a siliceous ore of copper. The blast is then turned on and the converter rotated until the tuyeres are covered. During the early stages of the blow (the slagging period) the ferrous sulfide in the matte is oxidized preferentially, because of its lower free energy of formation as compared with cuprous sulfide:

$$2FeS + 3O_2 \longrightarrow 2FeO + 2SO_2$$

The ferrous oxide produced combines with the siliceous flux to form a slag:

$$FeO + SiO_2 \longrightarrow FeO + SiO_2$$

The reaction furnishes sufficient heat to maintain the desired temperature and, in fact cold copper bearing material in the form of scrap, or matte skulls are added to prevent overheating and damage to the converter lining.

At the end of the slagging period, when all the ferrous sulfide has been oxidized and slagged, the bottom of the bath contains nearly pure

* These approximate figures apply to large horizontal converters. Quantities are smaller with upright converters which are rare today.

cuprous sulfide (white metal). In normal practice the charge is blown almost to white metal (30 to 180 minutes) and the converter is then rotated and most of the slag poured off. A new charge and fresh flux are then added and blowing and pouring of slag are repeated until the converter is filled with white metal. The last of the iron is removed as completely as possible, and the copper blow started.

The copper blow converts the white metal to blister copper:

$$Cu_2S + O_2 \longrightarrow 2Cu + SO_2$$

the sulfur oxidizing preferentially to the copper. If the blow is continued too long, the copper begins to oxidize; if too short, the sulfur is not completely oxidized.

The Pierce-Smith converter consists of a cylindrical steel shell mounted on trunnions at either end which permits rotation of the converter around the long axis. Figure 24.1 is a picture of a 13 by 30 foot converter, a common size. Figure 24.2 is a sketch of a typical converter aisle cross section. Air enters through tuyeres connected to the wind box by air pipe and flexible coupling. The tuyeres are usually 1 to 1-1/2 inches in diameter and 8 to 12 inches apart. They are placed high enough above the bottom to clear the level of the metal at the finish of the conversion. Frequent punching of the tuyeres is necessary to keep the air inlets clear.

Siliceous flux may be added to the converter in three ways:

1. By a steel scoop or boat handled by a crane which pours the material into the mouth of the converter,
2. By a chute from an overhead bin,

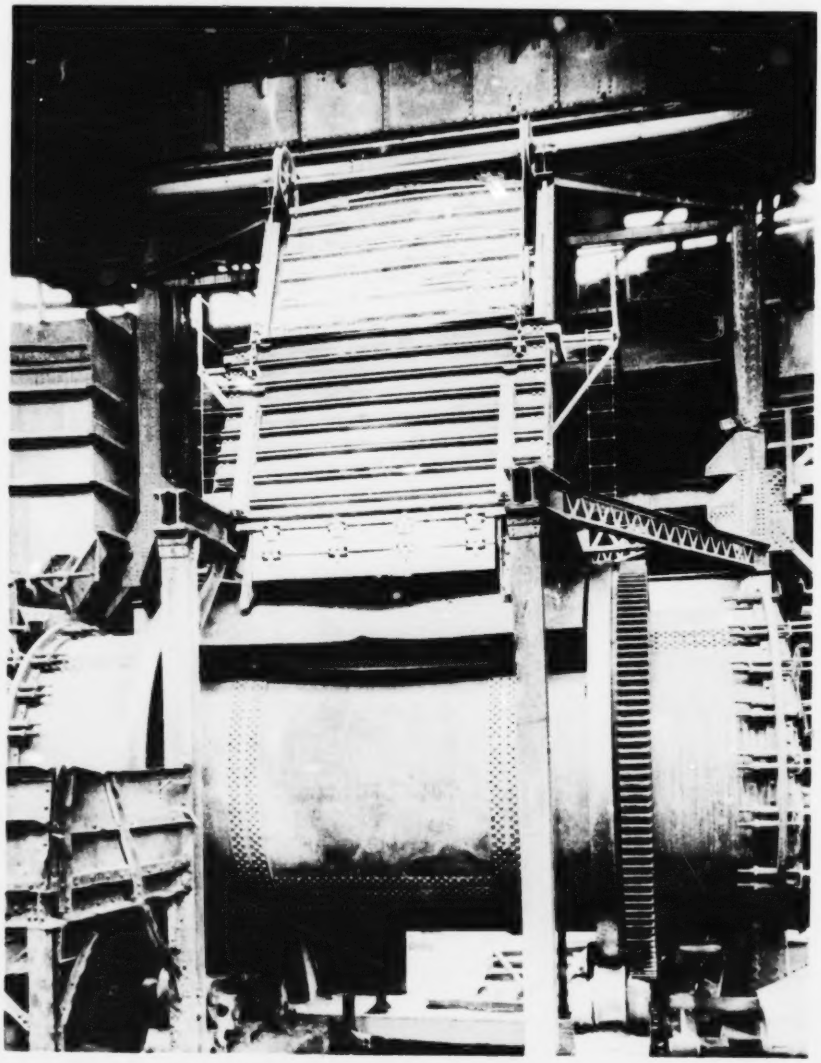


FIGURE 24.1 ELEVATION OF A PIERCE-SMITH CONVERTER

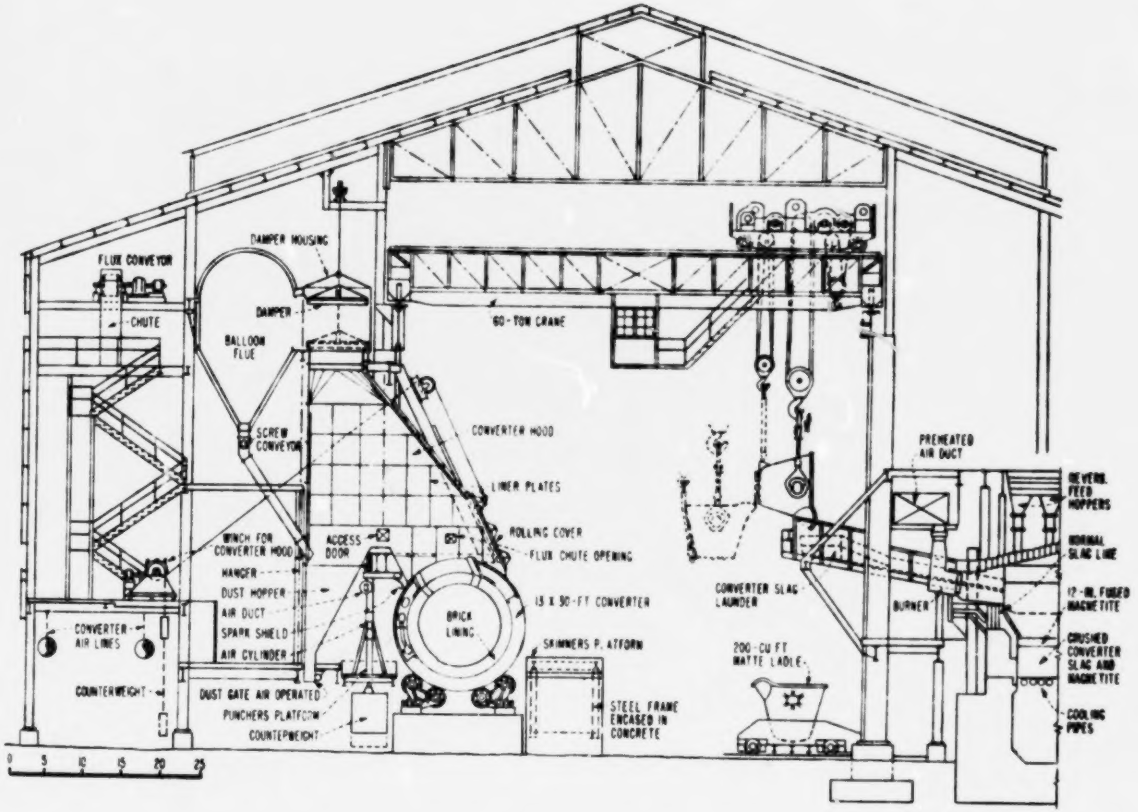

FLUX CONVEYOR
CHUTE
DAMPER HOUSING
DAMPER
BALLOON FLUE
SCREW CONVEYOR
60-TON CRANE
CONVERTER HOOD
LINER PLATES
ROLLING COVER
FLUX CHUTE OPENING
WINCH FOR CONVERTER HOOD
ACCESS DOOR
HANGER
DUST HOPPER
AIR DUCT
SPARK SHIELD
AIR CYLINDER
BRICK LINING
13 X 30-FT CONVERTER
SKIMMERS PLATFORM
CONVERTER AIR LINES
COUNTERWEIGHT
DUST GATE AIR OPERATED
PUNCHERS PLATFORM
COUNTERWEIGHT
STEEL FRAME ENCASED IN CONCRETE
CONVERTER SLAG LAUNDER
200-CU FT MATTE LADLE
PREHEATED AIR DUCT
REVERB. FEED HOPPERS
NORMAL SLAG LINE
BURNER
12-IN. FUSED MAGNETITE
CRUSHED CONVERTER SLAG AND MAGNETITE
COOLING PIPES
0
5
10
15
20
25

FIGURE 24.2 CONVERTER AISLE CROSS-SECTION

3. By a Gar gun which blows finely crushed silica into the converter through a tube inserted at one end.

When the converter cycle is finished the converter is tilted to discharge the copper metal into ladles. It is then transferred to the anode furnace and casting machines. The products of the converter are blister copper containing 99 percent copper, slag, and flue dust and gas. Converter slags are essentially iron silicates with some alumina and magnesia, but contain up to 5 percent copper. To avoid the loss of this copper, converter slags are used to flux the reverberatory furnaces or are solidified, broken up, and added to the furnace charge.

Flue gases laden with dust and fumes are captured at the converter mouth by either air-cooled or water-cooled hoods. Sufficient dilution air is introduced to cool the gases before entrance into large balloon flues leading to the primary gas cleaners. The gases consist principally of N_2, O_2, and SO_2. The production of SO_2 varies within the converter cycle and occurs only during the blowing periods. During the slagging blow, SO_2 concentration may be as high as 12 percent at the converter mouth, and during the finish blow as high as 18 percent. After dilution, SO_2 concentration varies from 2 to 10 percent at different stages of the converter cycle with an average of about 4 to 6 percent.

Fumes present in the flue gases are volitalized oxides of arsenic, antimony and lead and certain metallic sulfates and sulfuric acid. The dust from the converter contains as much as 45 percent copper. This copper and by-product arsenious oxide are collected in the flues and the primary dust collector. Dust concentration in the converter off gasses may average as high [illegible] gr/scf, which for a large converter would produce 15 tons of particulates per day.

24.2 Process Control Operation

The converter operation is a batch process. The parameters depend upon the converter size and the matte tenor. For instance, a 13-by-30 foot Pierce-Smith converter holds 200 tons of matte. With 40 percent matte the capacity is about 120 tons of copper per day with 12-hour operating cycles. Table 24.1 shows a typical operating schedule. Within moderate limits, the daily capacity increases 5 tons for each 1 percent increase in matte tenor and decreases 5 tons for each 1,000 ft. increase in altitude.

The theoretical quantity of oxygen per ton of copper produced can be calculated. However, excess air of around 50 percent at 12 to 15 psi is supplied to the converter and the volume is approximately 150,000 acf/ton of blister produced. Both the theoretical and actual amount vary with the grade of matte used. For the converter schedule outlined in Table 24.1, approximately 9,000,000 acf of air are required per cycle with an average flow rate of 15,000 acfm during the 10.1-hr blow period. The use of oxygen enriched air results in a substantial decrease in air requirements.

Infiltration of dilution air is permitted at the hood covering the mouth of the converter in order to cool the hot gases. For air cooled hoods, dilution air can be as much as four times the actual converter gas volume. In the case of tight fitting water cooled hoods, the dilution air may be only half the volume of the converter gas.

Operating temperatures within the converter are closely controlled in the range from 2,200 to 2,300°F by adding cold material to the oxidizing material as required. After dilution the flue gas temperatures are in the range 600 to 700°F with properly adjusted hoods. With excess dilution the temperatures are lower.

TABLE 24.1

TYPICAL OPERATING SCHEDULE FOR A CONVERTER BATCH USING A 40% MATTE

Work Done	Converter Blowing		Not Blowing		Cumulative Time	
	Hr.	Min.	Hr.	Min.	Hr.	Min.
Charge 6 tons matte shells						
Charge 6 ladles (72 tons) matte						
Charge 12 tons silica flux	1	30	-	-	-	-
Skim 3 pots (27 tons) slag	-	-	-	15	1	45
Charge 2 ladles (24 tons) matte						
Charge 4 tons converter cleanup						
Charge 8 tons silica flux	1	15	-	-	3	-
Skim 2 pots (18 tons) slag	-	-	-	10	3	10
Charge 2 ladles (24 tons) matte						
Charge 6 tons copper slag						
Charge 7 tons silica flux	1	05	-	-	4	15
Skim 2 pots (18 tons) slag	-	-	-	10	4	25
Charge 1 ladle (12 tons) matte						
Charge 3 tons matte shells						
Charge 6 tons silica flux	-	55	-	-	5	20
Skim 2 pots (18 tons) slag	-	-	-	10	5	30
Charge 1 ladle (12 tons) matte						
Charge 5 tons silica flux	1	-	-	-	6	30
Skim 1 ladle (9 tons) slag	-	-	-	5	6	35
Final Blow	-	20	-	-	6	55
Skim 1 ladle (9 tons) slag	-	-	-	10	7	05
Charge 4 tons scrap copper						
Blowing to copper	3	45	-	-	10	50
Charge 1 ton 90% silica flux (to remove lead)						
Blow to high blister	-	15	-	-	11	05
Skim oxidized slag (6 tons)	-	-	-	5	11	10
Transfer copper to pouring ladle	-	-	-	15	11	25
Cleaning tuyeres, silica gun and adding new matte charge	-	-	-	20	11	45
Total time	10	05	1	40	11	45
Total matte			144 tons			
Total silica flux			38 tons			
Total cold material			17 tons			
Total blister produced			60 tons			
Total slag produced			11 pots or 99 tons			

The operating variables for a given converter and gas recovery system are the quantity and tenor of the matte, the converter charging and blowing schedule, operating temperature and quantity of dilution air. All but the last of these are carefully controlled by the metallurgist in charge to produce the most desirable and economical product. Only the quantity of dilution air is outside the purview of the metallurgist and subject to other considerations. With acid plant SO_2 recovery systems dilution air will be reduced to a minimum commensurate with the requirement for cooling, but without acid plant recovery systems dilution air will increase to a maximum commensurate with flue and air cleaning capacity.

24.3 Enforcement Procedure

Emissions from the converter consist of sulfur dioxide gas and particulates. The gas composition is on the order of 4 to 6 percent SO_2. The dust loading is on the order of 3 to 10 gr/scf. Air pollution abatement equipment is used on almost all plants to remove the dust and many plants have sulfuric acid recovery facilities to remove sulfur dioxide from the gas stream.

The objective of copper converter operation inspection is to establish compliance with the sulfur dioxide and particulate emission regulations. In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design levels.

Converter and converter emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to plant inspection. Production levels, converter feed weight rates and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on the instrument panels.

Converters may have a control booth near the unit for process monitoring. The enforcement official should have little difficulty assessing the current operating status of the converter by observing the many recorders, gauges and log sheets which are normally kept.

Of primary importance for the enforcement of air pollution emission regulations is the process weight. With the mass rate and sulfur content of the feed, the SO_2 emissions can be computed (assume negligible content in copper and slag).

There is little that can be noted on instrument panels regarding the amount of particulates emitted to the atmosphere, although some plants will have a smoke density meter which may be used to determine relative particulate emissions from one visit to another. The enforcement official shouls note the operational parameters of the air pollution control devices.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plumes and if in excess of allowable limits, take appropriate action.

Building openings should be observed for evidence of escape of inadequately captured process dust and if noted, determine point(s) or origin and require corrective action.

The enforcement official should complete the Inspector's Worksheet for the converter.

INSPECTORS WORKSHEET

FOR COPPER CONVERTERS

Plant Id.____

Date of this Inspection______________Date of last Inspection________

No. of converters_______

Total capacity_________tons/hr Feed____________tons/hr copper

Type of converter____________________________________

Sulfur content of feed________%

ABATEMENT EQUIPMENT - Particulates

Pressure Drop________in. H_2O

Flow rate______________scfm

Inlet Temperature_________°F

Spark Rate______________spm

Collection Efficiency__________% Grain loading____________gr/scf

Year Installed__________

Opacity reading on stack_________%

DIAGRAM OF CONVERTER, PARTICULATE CONTROL EQUIPMENT SO_2 PLANT AND STACK

(Use separate sheet if necessary.)

GENERAL OBSERVATIONS:

Is hood volume adequate?____________________

SO_2odor?_________________________________

Leaks, holes, etc.?__________________________

Time In_______________________ Time Out_______________

PART IV

LEAD SMELTING

PART IV

LEAD SMELTING

Lead mining and refining ranks as the fifth largest basic metallurgical industry. Lead is one of the most useful metals, its major uses include automobile storage batteries, gasoline additives, building and construction, and small arms ammunition. Lead is also considered to be a strategic and critical material and is one of the stockpiled metals. Essentially all lead ores are mined underground and are concentrated, or beneficiated, at the mine site. The common lead minerals are galena (lead sulfide), cerussite (lead carbonate), and anglesite (lead sulfate). Galena is the most abundant lead mineral and is usually found associated with zinc, silver, gold, iron, and other minerals.

The domestic lead supply is derived from domestic mine production, imported ores and concentrates, imported metal, and secondary domestic production. The 1968 apparent demand of 1.4 million tons was supplied as follows: domestically refined primary lead - 35 percent, imports - 24 percent, secondary domestic production - 39 percent, and the remaining 2 percent from government stockpile releases.

Table IV-1 shows the 1968 U. S. lead smelters and refineries and their salient process identification.

The anticipated annual demand growth rate is about two percent and the forecast demand for the year 2000 ranges between 2.5 to 4.1 million tons. Environmental and economic considerations and changing use patterns could have major impact on the consumption patterns and demand rates.

Table IV-1

SURVEY OF UNITED STATES LEAD PRODUCTION IN 1968

	LEAD SMELTERS								LEAD REFINERIES					
Company Name	Name/ Location of Smelter	Year First Operated	Type of Roast/ Sinter Plant	H_2SO_4 (100%) Annual Capacity (tons)	Type of Smelter	Lead Slag Treatment	Lead Bullion Production (1968)		Name/ Location of Refinery	Year First Operated	Type of Refining	Refined Lead Production (1968)		By-Products
							Annual Capacity	Actual Production				Annual Capacity	Actual Production	
American Smelting & Refining Company	East Helena, Montana	1888	Dwight Lloyd - Up Draft		Conventional	Zinc Fuming Furnace	97,975	37,650						
American Smelting & Refining Company	El Paso, Texas	1887	Dwight Lloyd - Down Draft		Conventional	Zinc Fuming Furnace	97,975	48,080						
American Smelting & Refining Company	Glover, Missouri	1968	Dwight Lloyd - Up Draft		Conventional	Not Treated	81,650	4,080	Glover, Missouri	1968	Pyro	81,650	3,800	Au, Ag
American Smelting & Refining Company	Selby, California	1885	Dwight Lloyd - Down Draft	10,885	Conventional	Zinc Fuming Furnace	65,315	28,575	Selby, California	1888	Pyro	65,315	29,480	Au, Ag, Bi, Sb, Sn
American Smelting & Refining Company									Omaha, Nebraska	1870	Pyro	163,300	98,520	Au, Ag, Bi, Sb
Bunker Hill Co.	Bunker Hill, Idaho	1917	Dwight Lloyd - Down Draft		Conventional	Zinc Fuming Furnace	113,035	111,220	Bunker Hill, Idaho	1917	Pyro	111,220	111,220	Au, Ag, Cd, Cu, Sb
International Smelting & Refining Co.	Tooele, Utah	1912	Dwight Lloyd - Down Draft		Conventional	Zinc Fuming Furnace	59,875	33,080						
Missouri Lead Operating Company	Boss, Missouri	1968	Up Draft	47,175	Conventional	Diluent	90,720	19,050	Boss, Missouri	1968	Pyro	90,720	17,265	Ag, Cu
St. Joseph Lead Co.	Herculaneum, Missouri	1891	Dwight Lloyd - Down Draft	99,335	Conventional	Not Treated	204,115	155,130	Herculaneum, Missouri	1891	Pyro	200,115	155,130	Ag
U. S. Smelting, Refining & Mining Co.									East Chicago, Indiana		Electro	36,293	32,190	

Copper, gold, silver, and zinc are the major co- or by-products of lead production. The minor by-products consist of antimony, bismuth, cadmium, arsenic, sulfur, tellurium, gallium, germanium, indium, selenium, and fluorspar. Concentrator tailings may be used for highways, railroads and agriculture. Smelter slags are valued as construction material.

There are several terms and grades that define lead in terms of degree of purity, composition of impurities, and the size and shape of the product marketed.

Refined lead is 99.85 percent pure and is marketed in seven grades: corroding lead, chemical lead, acid lead, copper lead, and common desilverized lead; also antimony and tin alloys are classified as antimonial or hard-lead, white metals, fusible alloys, and copper alloys as leaded brasses or bronzes. The final product may be 1-ton blocks, 100-pound lead pigs, 25-pound caulking lead strings, powder form such as litharge and red lead oxide, or liquid tetraethyl lead.

Primary lead production is a sequence of physical-chemical processes that involves the mining and concentrating of the naturally occurring lead mineral, mostly as sulfide, the preparatory steps that are necessary for reducing lead to the metal form, the pyro-reduction process itself and the subsequent lead purification or refining.

25. MATERIAL HANDLING

The possible emissions will be particulates. Fugitive dust regulations will govern.

25.1 Process Description

Material handling is an important aspect of lead production in terms of bulk, diversity of equipment as well as the magnitude of the problem associated with airborne particulates and their control. Lead production is the process of separating 5 to 7 pounds of lead from about 100 pounds of mine ore.

Lead ore is mined underground and then transported to the surface where the first and most substantial bulk reduction, ore concentration, normally occurs. The concentrating, or milling operation consists of ore size reduction by grinding, crushing, and separation. Feeders convey the ore to large bins for blending and storing. Further size reduction takes place in wet-ball mills. The silt-like ore from the ball mill is classified and separated from coarse material and is pumped as a water slurry to flotation cells where the pulp is conditioned by additives. Large propellers stir the solution and the lead bearing minerals separate and float to the surface where they are skimmed off. The non-lead portion of the slurry, called tailings, is treated in cyclone separators to remove fines from the sand. The clean sand then may be pumped back into the mine and the fines to a settling pond.

Once separated, the ore concentrates are thickened in settling tanks and the slurry is fed to vacuum drum filters which reduce the moisture content to about seven percent. The concentration is now complete and the lead content has been upgraded from an average of 5 to 7 percent to about 65 percent.

The concentrates are transported to the smelter site and are stored in bins. Proper proportions of concentrates, fluxes, coke breeze, sinter dust, and crude ore, as necessary, are mixed and pelletized. Conveyor belts carry the pelletized mixture to the sintering unit, which removes most of the sulfur by roasting, and agglomerates it into a porous mass called sinter. The fused sinter is crushed and the dust recovered and recycled. The sinter, now ready for the blast furnace, is mixed with coke and is conveyed to the blast furnace.

Blast furnace products consist normally of four liquids that are discharged from the bottom: lead metal, matte, speiss, and slag. The lead usually goes to refining, and the matte and speiss to the dross furnace. Slag is removed separately to the fuming furnace for recovery of lead and zinc. Some slag from the fuming furnace may be recycled, the rest goes to waste. The dross, matte and sepiss from the lead refinery goes to the reverberatory furnace where lead is recovered and recycled; matte and speiss are then shipped to a copper smelter for copper recovery. Lead metal is further refined in kettles where other metals and trace materials are recovered. The final product is refined lead.

Some lead smelters operate such other equipment as cadmium roasters, deleading kilns, and slag fuming furnaces. Some slag from the fuming furnace, where lead and zinc are recovered, may be recycled but the rest goes to waste.

The material handling equipment may include such primary means of transportation as rail, truck, ships, barges, and pipelines. The secondary and more highly specialized equipment includes conveyors, overhead cranes, clamshell loaders, and cars. Modes of material storage include piles, bins, hoppers, kettles, settling tanks, and ponds. Process equipment includes crushers, grinders, ball mills, vibrating screens, vacuum filter drums, sinter machines, and furnaces. Figure 25.1 depicts principal emission points. Tables 25.1 and 25.2 summarize the pertinent lead

TABLE 25.1

LEAD BLAST FURNACE DATA

	A.S.&R. No. 1	A.S.&R. No. 2	A.S.&R. No. 3	A.S.&R. No. 4	A.S.&R. No. 5
Furnace Data					
Length and width at stock line, inside	16 ft. 10 in. x 8 ft.	16 ft. x 6 ft. 9 in.	15 ft. 3 in. x 5 ft. 8 in.	16 ft. 10 in. x 8 ft. 6 in.	15 ft. 3 in. x 6 ft. 3 in.
Length and width at tuyere line, inside	16 ft. 10 in. x 48 in.	16 ft. x 48 in.	15 ft. 3 in. x 5 ft. 6 in.	16 ft. 10 in. x 4 ft.	15 ft. 3 in. x 4 ft. 6 in.
Height, tuyeres to feed floor	27 ft. 10-1/2 in.	24 ft. 1 in.	27 ft.	28 ft. 3 in.	24 ft. 6-1/2 in.
Distance, tuyeres to slag tap	13-1/3 in.	11 in.	14 in.	9 in.	15 in.
Depth of hearth	6 in. below slag tap	3 ft. 7 in. (2 furnaces) 3 ft. 1 in. (1 furnace)	21 in.	2 ft. 3 in.	2 ft. 6 in.
Single or double tier of jackets	Double	Single	Double	Single	Single
Height of water jacket zone	8 ft. 6 in.	6 ft. 4-1/2 in (2 furnaces) 6 ft. 6 in. (1 furnace)	9 ft.	6 ft. 9 in.	7 ft.
Number and size of tuyeres	15 per side, 4 in.	28: 4-1/2 in. (2 furnaces) 24: 4-1/2 in. (1 furnace)	24 - 4 in.	29 - 2-1/2 in.	24 - 4 in.
Type of top	Thimble	Open	Thimble	Thimble	Thimble
Number of settlers before slag pot	Two	Two	Two	Two	Two
Operating Data					
Volume of blast per minute	7500-9000 cu. ft.	7200 cu. ft.	7500 cu. ft.	9000 cu. ft.	7200 cu. ft.
Pressure of blast	35-50 oz.	40 oz.	40-45 oz.	46 oz.	45 oz.
Volume of cooling water	1500 gal. per min.	250 gal. per min.	850 gal. per min.	500 gal. per min.	--
Temperature of water overflow	100-110° F.	100° F.	140-160° F.	100° F.	190° F.
Charge Data					
Total wt. per 24 hr. exclusive of coke	440 tons	470 tons	450 tons	457 tons	550 tons
Per cent sinter in charge	70-80	88	85	45.8	95
Per cent limerock not included in sinter	5-10	None	None	11.9 pct.	0.2 pct. of total limerock used
Other constituents of charge, kind and wt.	Leady siliceous ore 10-12 pct. Scrap iron 3.5 pct.	Settler slag 4 pct. Plant by products 3 pct. Zinc plant residues 7 pct.	Foul slag 15 pct. Scrap iron 3 pct.	Scrap iron 3.8 pct. Siliceous ores 29.2 pct. Foul slag 9.3 pct.	Foul slag 16 tons - 24 hr. Scrap iron 8 tons - 24 hr.
Per cent of lead in charge exclusive of coke	26-28	34	30	17.4	30
Per cent of coke per cent of charge	13	10 regular 3 scrap	11	12.5	9.5
Product Data					
Slag, wt. per 24 hr.	275 metric tons	310 tons	275-300 tons	290 tons	245 tons
Method of disposing of slag	Dumped hot	Zinc fuming furnace	Zinc fuming furnace	Dumped hot	Dumped hot
Bullion, total wt. per 24 hr.					
Before drossing	--	115 tons	265-275 tons	188 tons	220 tons
After drossing	110 tons	90 tons	175 tons	150 tons	151 tons
Wt. dross per 24 hr.	85 tons	25 tons	90-100 tons	38 tons	68 tons
What additions are made to drossing kettle?	Soda ash, coke, litharge, sulfur, for decopperizing	300 lb. S for decopperizing per 60 tons bullion	Salt cake 5 pct. crushed coke 3 pct.	130 lb. S per 55 tons bullion Sawdust	Sulfur Petroleum coke Soda ash
Wt. primary matte, if any	None	None	None	None	None
Wt. primary speiss, if any	3 tons per day	7 tons per day	None	3 tons per 24 hr.	10 tons per 24 hr.
Dross Furnace Data					
Wt. dross charged per 24 hr.	85 tons	70 tons	90-100 tons	43 tons	77 tons
Kind and wt. of other additions	Additions made in drossing kettle	4 pct. soda ash 1 pct. coke breeze	Additions made in drossing kettle	Miscellaneous furnace speiss 22 tons siliceous ore 1.5 tons	Additions to drossing kettle + 1/2 ton litharge
Wt. bullion produced per 24 hr.	45 tons	45 tons	60 tons	23 tons	50 tons
Wt. matte-speiss produced per 24 hr.	30 tons	8 tons matte 15 tons speiss	25 tons matte 23 tons speiss	35 tons	21 tons
Wt. slag produced per 24 hr.	None	None	None	6 tons	None

Bunker Hill Kellogg, Idaho Furnace No. 3	Bunker Hill Kellogg, Idaho Furnaces 2 & 4	C.M.&S. Trail, B.C.	International Tooele, Utah	St. Joseph Lead Herculaneum, Mo.	U.S. Smelting Midvale, Utah
31 ft. x 5 ft. 9-1/2 in.	15 ft. x 3 ft. 9 in.	Length, 3 @ 15 ft. 2 @ 22 ft. 6 in. Width, 2 @ 6 ft. 4 in. 3 @ 6 ft. 10 in. 1 @ 10 ft.	15 ft. x 7 ft. 9 in.	10 ft. x 6 ft.	13 ft. 4 in. x 5 ft. 5 in.
31 ft. x 5 ft. 9-1/2 in.	15 ft. x 4 ft.	Length, 3 @ 15 ft. 3 @ 22 ft. 6 in. Width, 1 @ 4 ft. 3 @ 5 ft. 5 in. 1 @ 6 ft. 8 in. 1 @ 84-96 in.	15 ft. x 4 ft. 4 in.	10 ft. x 5 ft.	13 ft. 4 in. x 4 ft.
19 ft. 4 in.	19 ft. 4 in.	17 ft.	24 ft. 8 in.	19 ft. 5 in.	24 ft. 7-1/4 in.
20 in.	14 in.	14 in.	13 in.	14 in.	11 in.
1 ft. 8 in.	1 ft. 2 in.	2 ft. below bottom of tuyeres at lead well only	2 ft. 7-3/4 in.	2 ft. 4-3/4 in.	2 ft. 9 in.
Triple. 2 vertical 1 inclined	Double tier boshed out	4 with 2 1 with 1-1/2	Double	Single	Single
10 ft.	13 ft.	4 @ 13 ft. 1 @ 9-1/2 ft.	15 ft.	12 ft.	6 ft.
56 - 2-1/2 in.	20 - 4 in.	2 with 48 - 2-1/2 in. 2 with 72 - 2-1/2 in. 1 with 56 - 2-1/2 in.	24 - 4 in. on sides 2 - 3 in. at back 1 - 2 in. at front	24 - 5 in.	20 - 5 in.
Vertical center gas take-off charge fed at sides of take-off	End gas take-off. Center dump feed. Splitting rail	Hooded with central off-take	Open	Open	Open
One when slag goes to fuming furnace. Two when dumped	Same as No. 3	One	Two	One	Two
11,000 cu. ft.	8000 cu. ft.	2 @ 7000 cu. ft. 1 @ 8000 cu. ft. 2 @ 9000 cu. ft.	8500 cu. ft.	7000 cu. ft.	8000 cu. ft.
26 - 34 oz.	18 - 24 oz.	34 - 36 oz.	45 - 54 oz.	32 - 36 oz.	40 oz.
150 gal. per min. recirculated	350-450 gal. per min.	50 gal. per min. Nesmith Vaporizer	--	205 gal. per min.	480 gal. per min.
175° F.	75-175° F.	170° F.	150-180° F.	--	147° F.
350-650 tons	240-370 tons	350-550 tons depends on furnace size	550-580 tons	488 tons	575-625 tons
70-80	70-80	87	90	71.5	80-96
1-1/2 - 3 pct.	1-1/2 - 3 pct.	None	0-4 pct.	None	1-3 pct.
Foul slag 0 - 1/2 pct. Reverb. dross 0 - 1 pct. Misc. 0 - 5 pct. Zinc plant residue 10 - 25 pct. Dump slag 5 - 10 pct.		Pot shells 6.3 pct. Settler cleanings 1.9 pct. Miscellaneous 4.8 pct.	B.F. cleanings 3 pct. Bag house fume 1-1/2 pct. Conv. slag 1 pct. Ore 4 pct. Scrap iron 0.5-2.5 pct.	Slag 24 pct. Wind box lead 20 pct. Dross 50 pct. Forehearth cleanings 5.	Scrap iron 4 pct. Siliceous gold ore 1 - 5 pct.
25-40	25-40	31.2	20-30	49	24-28
10-12	10-14	11.5	10 - 11-1/2	8.5	9-10
400-450 tons (2 furnaces)		675 tons new slag 930 total	325-360 tons	195 tons	375-425 tons
To slag fuming or dumped hot		Zinc fuming furnace	Zinc fuming furnace	Granulated	Granulated
180-265 tons (2 furnaces)		415 tons	150-230 tons	217 tons	130-170 tons
170-240 tons (2 furnaces)		400 tons	110-180 tons	168 tons	105-134 tons
10-25 tons (2 furnaces)		15 tons	50-85 tons	49 tons	33-38 tons
15-25 tons coal per 100 ton kettle 100 lb. S per 90 tons bullion		None	Salt cake, coke breeze Finish with 500 lbs. to 120 tons Pb	None	Pyrite and sulfur
None		None	None	19 tons per day	None
4-10 tons per 24 hr. (2 furnaces)		None	None	None	4-8 tons per day
60 tons		45 tons Dross furnace operated 3-4 months yearly	50-80 tons	No dross furnace	33-39 tons
1-3 pct. silica ± 1 pct. coke. Add antimony skim to soften crusts when necessary		None	Added in dross kettle	--	400 lb. S + 300 lb. pyrite per 30 tons, stirred in kettle.
25-35 tons		13 tons	30-45 tons	--	24 tons
15-20 tons		15 tons	4 - 4-1/2 tons speiss 5 - 5-1/2 tons matte	--	10-12 tons
5-10 tons		9.5 tons	None	--	2 tons

TABLE 25.2

SINTERING DATA

	A.S.&R. No. 1	A.S.&R. No. 2	A.S.&R. No. 3	A.S.&R. No. 4	A.S.&R. No. 5	Bunker Hill Kellogg, Idaho	C.M.&S. Trail, B.C.	International Tooele, Utah	St. Joseph Lead Herculaneum, Mo.	U.S. Smelting Midvale, Utah
Number of Machines	9	9	6	4	4	9	14	10	8	6
Length of Wind Box	4 @ 38 ft. 2 @ 42 ft. 6 in. 3 @ 45 ft.	8 with 2 boxes 11 ft. long 1 with 4-11 ft. long	3 @ 11 ft. 3 @ 10 ft.	3 @ 31 ft. 1 @ 60 ft.	30 ft. (3 boxes) 32 ft. (4 boxes)	Two 11 ft. boxes	6 @ 22 ft. 8 @ 48 ft.	22 ft. (2 boxes)	22 ft.	22 ft. (2 boxes)
Overall Length of Machines	4 @ 57 ft. 3 in. 5 @ 63 ft. 3 in.	8 @ 32 ft. 5 in. 1 @ 54 ft. 9 in.	1 @ 40 ft. 2 @ 30 ft. 3 @ 22 ft.	3 @ 46 ft. 7-1/4 in. 1 @ 85 ft.	2 @ 53 ft. 2 @ 61 ft. 4-1/2 in.	40 ft. 8-1/2 in.	6 @ 40 ft. 8 @ 65 ft.	--	41 ft. 1-1/2 in.	40 ft. 5 in.
Size of Pallets	42 x 24 in.	42 x 24 in.	3 have 42 x 24 in. 3 have 63 x 24 in.	3 have 42 x 24 in. 1 has 63 x 24 in.	2 have 42 x 24 in. 2 have 63 x 24 in.	42 x 24 in.	42 x 24 in.	42 x 24 in.	42 x 24 in.	42 x 24 in.
Speed of Pallets in. per min.	First over 72-80 Second over 32	First over 37 Second over 24	36-50	3 @ 44 1 @ 55	2 @ 45 2 @ 38	First over 18-24 Second over 14-18	First over 36 Second over 24	25	20-27	28-35
Amount of Suction										
(a) 1st over Charge	10 in. water	12 in. water	10-12 in. water	11 in. water	12 in. water	8-12 in. water	12-14 in. water	8-11 in. water	11 in. water	10 in. water
(b) 2nd over Charge	12 in. water	8.5 in. water	13-14 in. water	14 in. water	10 in. water	8-12 in. water	12-14 in. water	6-8 in. water	9 in. water	8 in. water
Depth of Bed										
(a) 1st over Charge	3 in.	7 in.	4-1/2 in.	3-4 in.	5-1/4 in.	5 in.	6 in.	4-5 in.	5-1/2 in.	5 in.
(b) 2nd over Charge	12 in.	7-1/2 in.	8 in.	9 in.	7 in.	4-1/2 in.	9-10 in.	6-7 in.	5-1/2 in.	6 in.
Per Cent S in Feed										
(a) 1st over Charge	11-12	5.6	11.0	13.7	10	±13	11	9-12	10.8	10-12
(b) 2nd over Charge	4-5	3.4	4.5	7.0	5	±6.5	7	3.5-5.0	7.7	4.5-6.0
Per Cent S in Product										
(a) 1st over Charge	4-5	3.4	4.5	7.1	5	±7	7	4.5-6	7.7	4.5-6.0
(b) 2nd over Charge	1 to 1-1/2	0.8	1.9	1.3	1.9	±1.5	2	0.7-1.4	3.4	.8-1.5
Capacity per Machine Day										
(a) 1st over Charge	400 tons	270 tons	250 tons	3 @ 175 tons 1 @ 525 tons	350 tons (small machines)	± 120 tons	480 tons (long machines)	150 tons	285 tons	190-210
(b) 2nd over Charge	525 tons	140 tons	900 tons	1 @ 740 tons	550 tons (large machines)	±110 tons	396 tons (long machines)	130 tons	220 tons	240-275
Per Cent Limestone in Charge	15-20 includes limey ores	23	15-18	--	98.8 Pct. of total limestone	95-99 pct. of total limestone	6-11	4-15	0-2	2-3 pct. limestone + 13-16 pct. limesand 48 pct. CaO

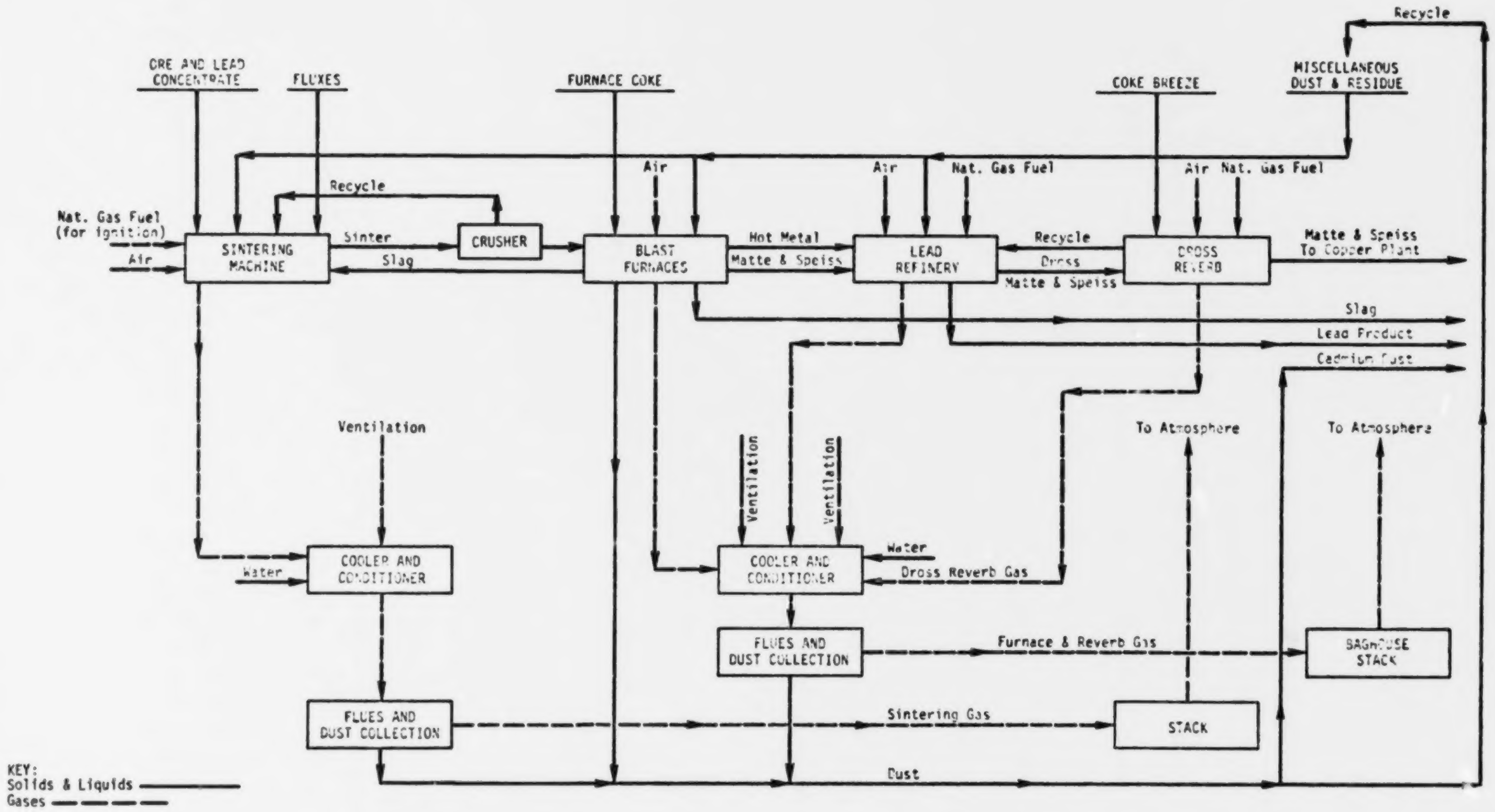

Recycle
ORE AND LEAD CONCENTRATE
FLUXES
FURNACE COKE
COKE BREEZE
MISCELLANEOUS DUST & RESIDUE
Air
Air
Nat. Gas Fuel
Air
Nat. Gas Fuel
Recycle
Nat. Gas Fuel (for ignition)
Air
SINTERING MACHINE
Sinter
Slag
CRUSHER
BLAST FURNACES
Hot Metal
Matte & Speiss
LEAD REFINERY
Recycle
Dross
Matte & Speiss
DROSS REVERB
Matte & Speiss To Copper Plant
Slag
Lead Product
Cadmium Dust
Ventilation
To Atmosphere
To Atmosphere
Ventilation
Ventilation
Water
COOLER AND CONDITIONER
Water
COOLER AND CONDITIONER
Dross Reverb Gas
FLUES AND DUST COLLECTION
Furnace & Reverb Gas
BAGHOUSE STACK
FLUES AND DUST COLLECTION
Sintering Gas
STACK
Dust
KEY:
Solids & Liquids
Gases

FIGURE 25.1 LEAD PLANT EMISSION SOURCE DIAGRAM

blast furnace and sintering machine equipment data, respectively, by companies for 1968.

Figure 25.2 shows a typical material flow diagram of the total process involved in lead production.

Of primary concern in material handling is the containment and control of fugitive dusts which are generated when sufficiently fine size material is exposed to moving air. Such material may be stationary or in transit. Most dusts become airborne during periods of loading and unloading at points of transfer.

25.2 Process Control Operation

There are two effective and widespread methods of dust control: water sprays and physical capture and confinement by such means as hoods and other enclosures.

Some of the most important variables affecting dust emission into the air are particle size and density, the relative velocity between particle and air, and the surface area exposed to air per unit volume of dust. Total emission control includes, in the final analysis, the manipulation of all the variables affecting emission rates.

Table 25.3 is a summary of the principal materials involved in lead production. It is relatively simple to identify the major material handling process variables, namely mass flow rates, composition, size distribution, plant physical layout, and material flow paths at an individual plant.

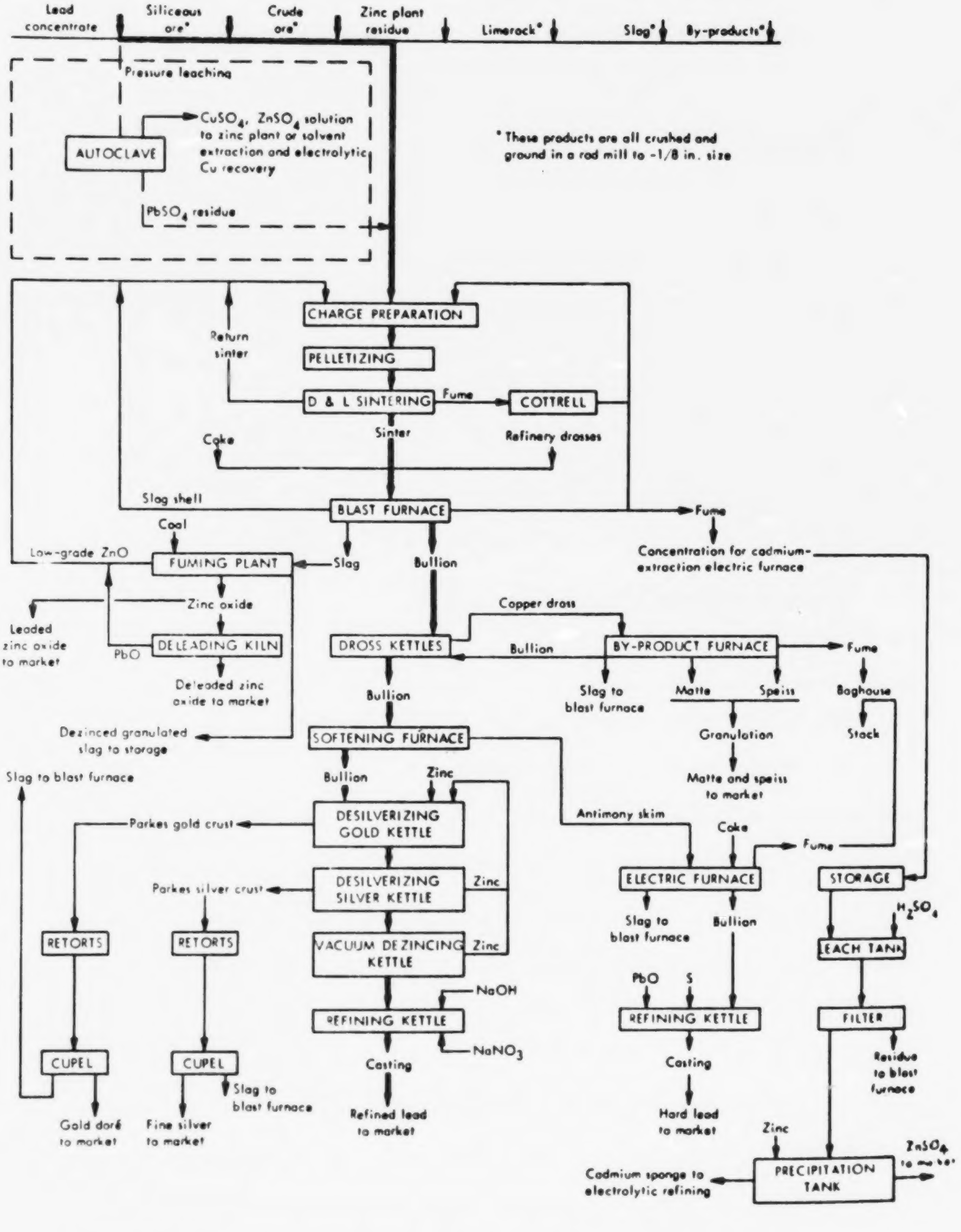

Lead concentrate
Siliceous ore*
Crude ore*
Zinc plant residue
Limerock*
Slag*
By-products*
Pressure leaching
AUTOCLAVE
$CuSO_4$, $ZnSO_4$ solution to zinc plant or solvent extraction and electrolytic Cu recovery
$PbSO_4$ residue
* These products are all crushed and ground in a rod mill to -1/8 in. size
CHARGE PREPARATION
Return sinter
PELLETIZING
D & L SINTERING
Fume
COTTRELL
Sinter
Coke
Refinery drosses
Slag shell
BLAST FURNACE
Fume
Concentration for cadmium-extraction electric furnace
Coal
Low-grade ZnO
FUMING PLANT
Slag
Bullion
Zinc oxide
Leaded zinc oxide to market
PbO
DELEADING KILN
Deleaded zinc oxide to market
Dezinced granulated slag to storage
Copper dross
DROSS KETTLES
Bullion
BY-PRODUCT FURNACE
Fume
Slag to blast furnace
Matte
Speiss
Baghouse
Granulation
Stack
Matte and speiss to market
Bullion
SOFTENING FURNACE
Slag to blast furnace
Bullion
Zinc
Antimony skim
Coke
Fume
Parkes gold crust
DESILVERIZING GOLD KETTLE
DESILVERIZING SILVER KETTLE
Zinc
Parkes silver crust
ELECTRIC FURNACE
STORAGE
H_2SO_4
RETORTS
RETORTS
VACUUM DEZINCING KETTLE
Zinc
Slag to blast furnace
Bullion
LEACH TANK
NaOH
PbO
S
REFINING KETTLE
REFINING KETTLE
FILTER
$NaNO_3$
CUPEL
CUPEL
Casting
Casting
Residue to blast furnace
Slag to blast furnace
Gold doré to market
Fine silver to market
Refined lead to market
Hard lead to market
Zinc
$ZnSO_4$ to market
Cadmium sponge to electrolytic refining
PRECIPITATION TANK

FIGURE 25.2 LEAD PRODUCTION PROCESS FLOW DIAGRAM

Table 25.3 PRINCIPAL MATERIALS OF LEAD PRODUCTION AND THEIR ESTIMATED RELATIVE QUANTITIES

Material	Weight (tons)
Lead ore	100
Ore concentrate	15 to 20
Ore tailings	80 to 85
Lead metal	5 to 7
Blast furnace slag	8 to 15
Slag fuming furnace slag	7 to 14
Fluxes and additives	----
Coke	1 to 2
Speiss and matte	2 to 3
Other	2 to 3

25.3 Enforcement Procedure

The following enforcement procudure lists general observations which can be made of materials handling schemes at lead plants. At many integrated plants, fugitive dust losses may account for more atmospheric emission of particulate matter than the sintering and blast furnaces which have air pollution control equipment. Because of the different methods of handling raw materials, product, and tailings, the following general guides are suggested:

1. Trace the flow of raw materials from the time they arrive at the plant until they enter the blast or reverberatory furnaces.
2. From a distance observe the raw material and processed materials for dust clouds either from roadways, stock piles, transfer points, crushing and screening operations, slag dumping,

plant construction activities, etc. These sources are generally not continuous emitters, but depend on the activity schedule.

3. Make records of the dusty areas for a close-up inspection. These observations should be made from beyond the plant perimeter on a hillside overlooking the entire complex, if possible.
4. Observe the raw material stock piles when the wind is blowing and note any entrained dust.
5. Observe the material moving methods at the stockpiles.
6. Note any dust emissions at the bulk unloading stations.
7. If cranes, belts, or bulldozers are used to move the raw materials, note any major dust clouds.
8. Make notes on the lengths and locations of unpaved roadways. Ask if, and at what frequency, these roadways receive dust preventive treatment such as the application of water, oil, or calcium chloride. Observe the paved, macadamized and gravel roads for latent dust. Occasionally these roads may become burdened with dust and result in another source for fugitive dust.
9. Observe the transfer points along belt haulage ways. If no dust is noted, no further inspection is required here.

The Inspector's Worksheet which follows may be useful for record keeping. Interpretation of these observations is dependent upon the pertinent regulations governing fugitive dust emissions. Since many of these plants are located on large plots of land, it is important to discriminate between in-plant housekeeping problems and emissions which cross the property line.

INSPECTORS WORKSHEET

FOR RECEIVING, STORING AND HANDLING OF RAW MATERIALS

Plant Id.____

Date of this Inspection_____________Date of last Inspection______________

Type of Plant____

Capacity of Plant____

Source Location	Type Material	Wind Direction Wind Speed (mph)	Plume Description	Preventive Measures
Sample Concentrate belt loading	ore concentrate	SW/10	slightly visible dust	none
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				

26. CONCENTRATE DRYING

The possible emissions will be particulates. Likelihood of emissions is remote.

26.1 Process Description

The concentration operation for these various smelting processes is employed to separate sulfide minerals from waste rock. The drying mechanisms used to remove moisture from concentrate ores for lead production are generally not heated. Thus, the air pollution potential from this source is minimized. Most of the concentrate drying processes at lead plants use filtration drums to draw as much water from the concentrated ores as possible. This is done at room temperature and with no heat being added to the drum.

The raw ore arrives at the plant and is stored in various silos and bins for further processing. The ore may come from barges, shipping vessels, underground mines, or railroad cars. The material handling system is likely to have the most air pollution emissions at the concentrate building. Moisture content for the raw material is about 3 percent. The raw ore is then screened, crushed, and ground and sent through a flotation process to separate zinc ore and lead ore. Figure 26.1 shows a typical concentrator at a lead production plant. The final lead concentrate will assay about 67 percent lead, 5 percent zinc. The average moisture content of the filtered lead concentrate is 7 percent. Tailings from the lead concentrate assay will average about 55 percent zinc. The zinc concentrate filter cake has an average moisture content of about 10 percent.

26.2 Process Control Operation

Very few air pollution emissions occur from the lead concentrate operation. The concentrator plant is usually located away from the blast

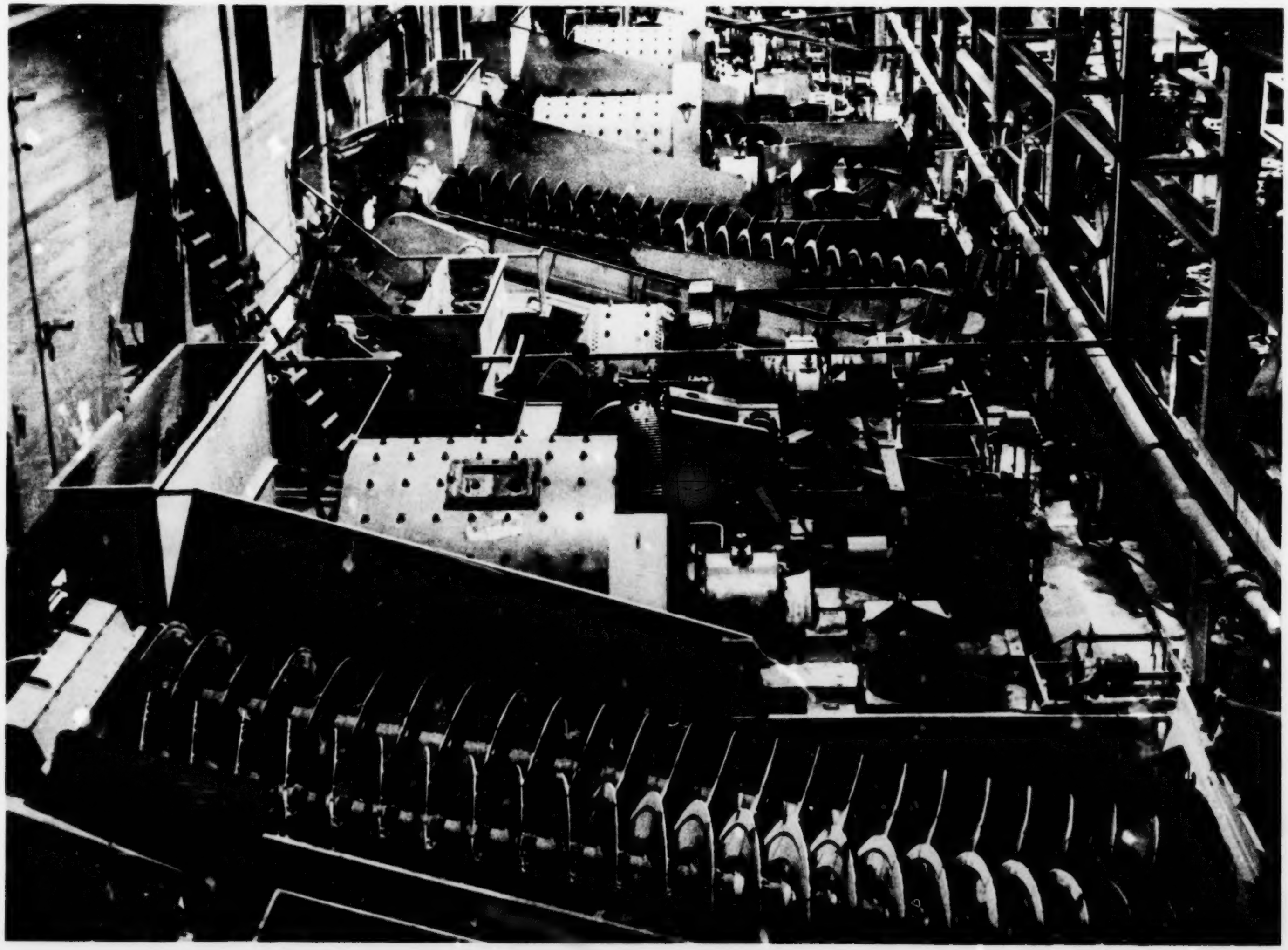


FIGURE 26.1 LEAD CONCENTRATE PLANT

furnace and sintering operations in a separate building. The few emissions that do occur from this operation are the result of the material handling of the bulk ores. Generally speaking, no air pollution control devices are installed at the concentrator plant. There are no detrimental off gases of any concern from the concentrate operation. The concentrate dewatering takes place on a filter drum at room temperature and emits nothing to the atmosphere.

26.3 Enforcement Procedure

The enforcement official should make a subjective type evaluation of the material handling system for the concentrate building. It is unlikely that any of the ore will be entrained by air and present a fugitive dust problem. The enforcement official should check the transfer points and the enclosed system of the storage hoppers.

The enforcement official should make note of the amount of material processed through the concentrate building for future comparisons. No atmospheric testing needs to be done at this particular process during the enforcement official's inspection visit.

If fugitive dust violations are apparent, take appropriate action.

27. CONCENTRATE SINTERING

This is the major point of sulfur emissions in the lead smelting process; however, individual plants may have sulfur recovery units. It is also a possible major source of particulate emissions if control equipment is not functioning properly.

27.1 Process Description

Sintering is a chemical and physical process that converts metal sulfides to metal oxides and fuses the concentrate into a porous mass, called calcine, that is suitable for reduction in a blast furnace. The main chemical reaction taking place on the sintering machine is the oxidation of lead and other metal sulfides. Heat is generated by these reactions and the oxidation is self-sustaining. Fuel, usually natural gas, is required to initiate the reaction. Process temperatures are kept below 1,400°F to prevent excessive loss of metals by vaporization, fusion of the clinker, and damage to the grating of the pallets.

The feed to the sintering machine consists of pelletized mixture of lead sulfide concentrate, high silica lead ores, recycled dust, coke breeze and fluxes. The flux usually consists of high grade limestone, silica and some steel scrap. The lead concentrate generally has 55 to 70 percent lead, 13 to 18.5 percent sulfur, up to 6.5 percent zinc, 0.5 to 4.0 percent copper, up to 5.0 percent iron and minor amounts of silica, lime, silver, gold, arsenic and others, depending on the source.

The pelletized feed is loaded on the continuous conveyor, is ignited and combustion is sustained by supplying air to the pellets. Combustion gases are removed, usually through sectionalized wind boxes, and the clinker cakes drop to a coarse breaker and screen at the discharge end of the machine. The oversized material is crushed and the fines are recycled to the feed end of the machine. The product is a fused porous sinter which contains most of the metals as oxides.

Off gases may contain 0.8 to 1.8 percent sulfur dioxide. This represents about 85 percent of the total sulfur present in the feed; solid by-products account for about 14 percent and the remaining one percent is distributed between blast and dross furnace effluents. In addition to sulfur oxides, the gases may contain air, water vapor, carbon dioxide, hydrogen fluoride, silicon tetra-fluoride and traces of other gases. Organic vapors from flotation reagents are also present. Fumes include the more volatile metal oxides such as arsenic, cadmium, selenium, and tellurium. Elemental sulfur may also be present. Fumes are condensed and collected with the dust. If the cadmium content reaches 12 percent or more, portions of the dust may be diverted to cadmium furnace. Off gas flow rates vary from 100 to 220 scfm per square foot of bed area.

Table 27.1 shows some emission rates from lead sintering machines.

Table 27.1 EMISSIONS FROM LEAD SINTERING MACHINES

		Off Gas		Emission Rates	
Plant No. (a)	Estimated Capacity for Lead Production (tons/yr)	Flow Rate (scfm)	Temperature (°F)	Sulfur Equivalent of Sulfur Oxides (tons/yr)	Dust Recovered (tons/day)
326.09	76,000			19,200	
1st stage	n.a.	8,200	300		--
2nd stage	n.a.	n.a.	n.a.		--
326.10	122,000	32,400	400	36,200	22
326.17	198,000	34,000	300	39,100	--
326.18	120,000	35,500	350	28,500	--
326.33	91,000	n.a.	300	33,800	--
326.34	42,000	n.a.	350	13,500	--

(a) From Systems Study of Arthur McGee.

A sectionalized windbox is installed beneath or above the pallet grate to regulate burning rates. Gases are drawn through the windbox into ducts leading to dust collection equipment. The reported sinter off gas temperatures range between 300° and 400°F. The collected sinter gases may be cooled by air dilution and conditioned by water quenching to prepare for dust collection by filtration or precipitation. After the dust collector the gases are either vented or fed to a sulfuric acid plant, in which case the high sulfur dioxide content gas is processed separately.

Sintering machines range in size from 3.5 by 22 feet to 10 by 103 feet and in capacities from 1.5 to 2.75 tons of charged material, 12 to 18 inches deep, per square foot of bed area per day. In most of the older and smaller machines, air is introduced from above and flows through the ore bed on the conveyor and captured in the windbox and duct system underneath. These are known as down-draft machines. The newer and larger machines, in which the air flow is the reverse, are known as up-draft machines. Figure 27.1 shows the process of a sintering unit.

Following the sinter machine the sinter is crushed to usable size and transported to storage or to the blast furnace. The fines are returned to the feed-end of the sinter machine where they are blended into the feed.

27.2 Process Control Operation

The most important process variable in the sinter machine is the temperature. Temperatures exceeding 1,400°F are to be avoided to prevent excessive loss of metals by volatilization, fusion of the clinker and damage to the grating of the pallets. To a limited extent, temperature control is achieved by limiting the sulfur content between 6 and 12 percent. Once oxidation is started, it becomes self-sustaining because the process is exothermic. Sulfur content is regulated by mixing with sulfur-free fluxes, such as silica, limestone, fume furnace slag and sinter. Excess air flow regulation provides additional control.

Relatively high dust carry-over is expected during the period of ignition and initial stages of the oxidation, especially if high or excess flow rates occur. Initially, when the feed is relatively cool, sufficient air (oxygen) is required for optimum reaction and later, when the feed fuses and reaches the upper temperature limit (1,400°F), excess air is

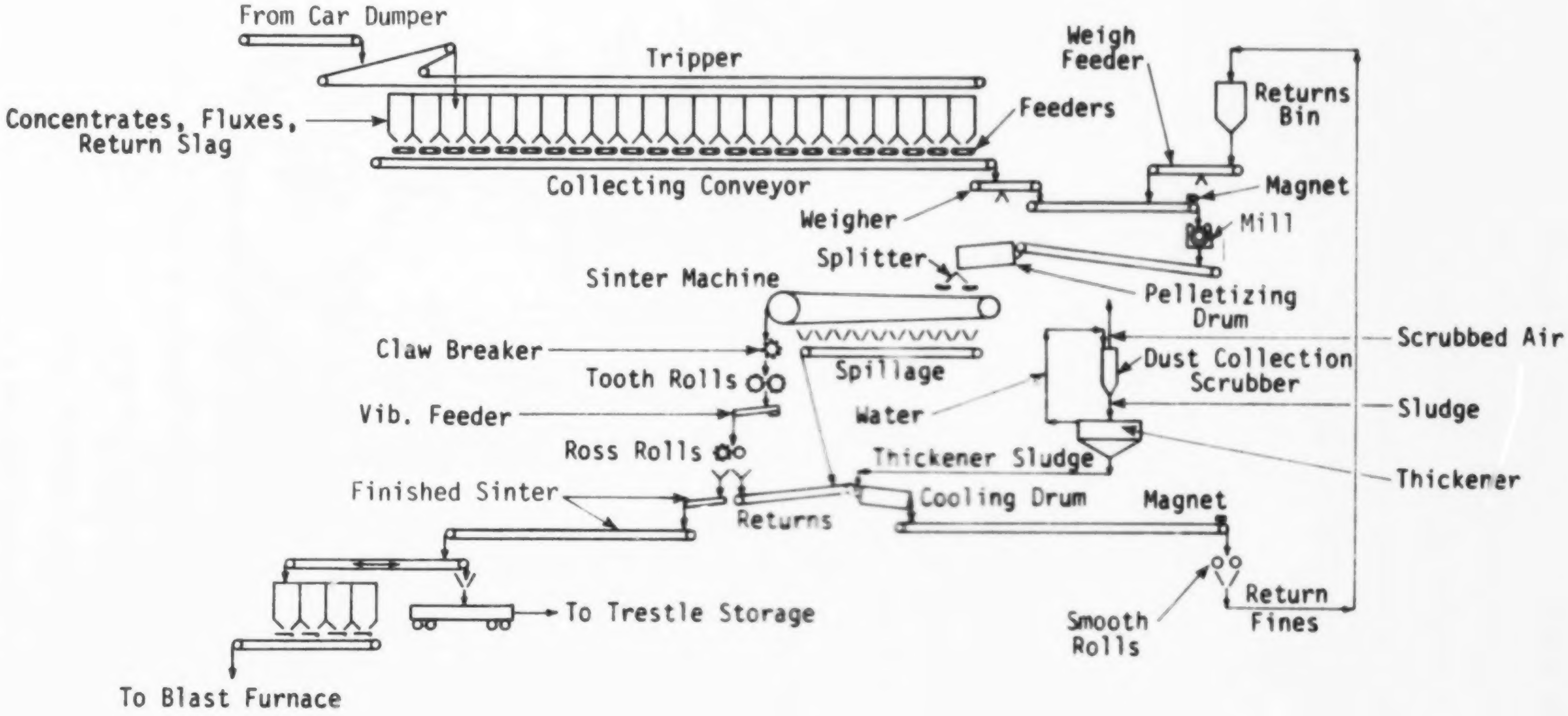

From Car Dumper
Tripper
Concentrates, Fluxes, Return Slag
Feeders
Collecting Conveyor
Weigh Feeder
Returns Bin
Magnet
Weigher
Mill
Splitter
Pelletizing Drum
Sinter Machine
Claw Breaker
Tooth Rolls
Spillage
Scrubbed Air
Dust Collection Scrubber
Water
Sludge
Vib. Feeder
Ross Rolls
Thickener Sludge
Thickener
Finished Sinter
Returns
Cooling Drum
Magnet
To Trestle Storage
Smooth Rolls
Return Fines
To Blast Furnace

FIGURE 27.1 LEAD SINTER PLANT

required to provide cooling. Volatilization of most metals occurs in the upper temperature ranges which is most likely to occur at low air flow rates. Sulfur dioxide emission is expected to reach maximum then tail off toward the end of the process. This process characteristic may be utilized to isolate high sulfur dioxide gases for acid plant processing.

Emission rates and concentrations can be expected to vary with feed composition, type of equipment used and operating skill. Particulate size distribution is also influenced by these factors.

The sinter crushing and screening operations at the machine-discharge have enormous particulate emission potential. These operations will be hooded and ducted to a control device.

27.3 Enforcement Procedure

The objectives of lead concentrate sintering operation inspection are to determine sulfur dioxide and particulate emission levels from the sintering operation and to evaluate the pollutant emission potential of this operation for varying production rates and operating conditions. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur oxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both sintering machine and emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels, sintering machine, and emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operators' daily log or are displayed on instrument panels.

The enforcement official should obtain specific information regarding the plant layout and plant capacity prior to his inspection of a sintering operation. Some of the operating variables of importance are:

1. The total feed rate to the sinter machine - these data are necessary in comparing process weight rate to allowable particulate emissions from industrial operations,
2. The percent sulfur content of the feed ore - most sintering plants will have these data readily available from previous ore assays, and,
3. The percent sulfur content of the sinter.

Many sintering plants will have sulfur oxide monitoring equipment on the sintering machines at various stages along the bed. This information may be used as a check against the sulfur oxide emissions calculated from the feed concentrate and sinter product sulfur mass balance. When sulfur recovery systems are used, performance data are needed. If valid information is not available from the plant operator, the enforcement official may elect to spot test the recovery system efficiency by means of indicator tubes (Part VII).

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of the dust control equipment stack plumes and if in excess of allowable limits, take appropriate action. Building openings should be observed for evidence of the escape of inadequately captured process dust. If noted, determine point(s) of origin and require corrective action.

The enforcement official should obtain off gas temperatures, flow rates, sulfur oxide concentration, particulate concentration, opacity, and other operating data that he can relate from one visit to another.

Upset conditions at sintering machines can cause elevated potential emissions. Depending on the particulate control equipment used, this could result in elevated particulate emissions. For example, a hole may develop in the sinter bed as a result of an improper distribution of the ore on the sinter bed. This hole will prevent complete sulfur oxidation and result in a small quantity of high sulfur content sinter. Continuous strip charts which record bed pressure on each wind box are available at most sintering plants. A sharp decrease in pressure on the strip charts would indicate that a hole has occurred. The major potential problem with frequent holes in the bed, over an extended period, is elevated particulate emission potential. The operating record strip charts can be reviewed to establish this operating problem. If a baghouse is used as the control device there is little likelihood of exceeding allowable emissions. If an electrostatic precipitator is the control device, stack tests may be required to establish emission data.

The enforcement official should complete the Inspector's Worksheet for lead sinter plants and make the calculations for total sulfur emissions from this operation. It should be pointed out that although most of the sulfur from lead smelting is emitted from the sinter plants, many state air pollution emissions standards are based on total sulfur emission from the smelting operation. The total smelting operation

INSPECTORS WORKSHEET

FOR LEAD SINTER PLANTS

GENERAL

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

OPERATING VARIABLES

Sinter Machine Feed Rate, including ore, concentrate flux coke, etc.____________ton/hr Output Rate________ton/hr

Sulfur Content of Feed Ore________%

Sinter Sulfur Content__________%

Moisture Content of Feed Ore________%

Temperature of Off Gases________°F

Sinter Machine Bed Speed________ft/hr

Number of Windboxes________, No. Updraft__________, No. Downdraft__________

Exhaust Gas Flow Rate__________scfm

Pressure Drop at Each Windbox; (in. H_2O)

1	2	3	4	5	6	7	8	9	10

Number of "Holes" Recorded in last day__________

Sulfur Dioxide Concentration: hi SO_2 gas_______%, remaining gas__________%

Type of SO_2 Control Device______________________________

Percent of Exhaust Gases Treated by SO_2 Control Device__________%

Particulate Control Device______________________________

____

Control Efficiencies: SO_2________% Particulate__________%

Inlet Temperature of Exhaust Gases to Control Device__________°F

Pressure Drop Across Control Device__________in. H_2O

VISUAL OBSERVATIONS

Physical condition of equipment:______________________________

____

Describe ductwork____

____

Maintenance Program____

Develop a diagram indicating gas flow from the sinter machine to atmosphere.

CALCULATIONS

% sulfur in feed x feed rate (lb/hr) = ____________lb/hr of sulfur.

hi SO_2 gas

concentration (%) x $\left[\frac{100 - \%\ \text{efficiency of acid plant}}{100}\right]$ x flow rate (scfm) x 5 = ___________lb/hr sulfur in acid stack.

remaining SO_2 gas

concentration (%) x flow rate (scfm) x 5 = __________sulfur, lb/hr.

If concentration is not available, take

(% S feed ore - % S calcine) x feed rate (lb/hr) =_______lb/hr net sulfur from sinter machine.

[net sulfur, (lb/hr)]-[hi SO_2 concentration x (collection eff. $\frac{\%}{100}$) x flow rate (scfm) x 5] = _______________lb/hr sulfur from sinter plant.

Time In____________________________________Time Out_______________________________ would include not only the sinter machines but also the blast furnace and the reverberatory furnaces. It has been estimated that about 90 percent of all sulfur emitted to the atmosphere will occur as a result of the sintering operation. The remaining 10 percent is divided between the blast furnace and the reverberatory operations.

On his first visit the enforcement official should develop a diagram indicating the gas flow of sulfur oxide gas streams from the process equipment to the atmosphere. Many lead manufacturing plants will combine the exhaust gas streams from the sinter plant, lead blast furnace, reverberatory furnaces, and other ancillary operations into one large abatement facility. Electrostatic precipitators or baghouses are frequently used to reduce particulate emissions from these operations.

28. ORE REDUCTION - BLAST FURNACE

This is a major potential particulate emissions and minor sulfur emission process. Particulate emissions are mainly a function of the adequacy of the control system.

28.1 Process Description

Lead oxide is reduced to metallic lead using carbon monoxide as a reducing agent. The process heat required is derived from coke combustion. The major chemical reactions that take place are:

$$C + O_2 \rightarrow CO_2 + \text{heat}$$

$$C + CO_2 + \text{heat} \rightarrow 2CO$$

$$PbO + CO + \text{heat} \rightarrow Pb + CO_2$$

Some iron, zinc and other oxides are also reduced. Liquid lead collects at the bottom of the furnace where it is drawn off. Slag floats on top of the metal and prevents further oxidation of lead. Other metal oxides react with silica to form slag. The blast furnace charge is a mixture of sinter, coke and some fluxes. Air is introduced through tuyeres at low pressure and ambient temperature near the furnace bottom. The air flow rate is related to furnace capacity and varies between 5,000 and 9,000 scfm.

The products from the blast furnace consist of liquids and gases. The liquids are drawn off at the bottom and the gases are vented at the top. There are four distinct liquids that comprise the bottom products: lead, matte, speiss and slag. Lead may be separated from matte and speiss and sent directly to the refinery or to the dross furnace with the matte and speiss. Slag is removed separately and is conveyed to a fuming furnace for recovery of lead and zinc.

Slag is a siliceous amalgam of many constituents. It contains 10 to 20 percent zinc, up to 2 percent lead and 3 percent sulfur.

Matte (metallic sulfides) contains 44 to 62 percent lead, 10 to 20 percent zinc, up to 13 percent sulfur, and lesser amounts of iron, copper and silica.

Speiss (metallic arsenides) contains 55 to 64 percent copper, 8 to 18 percent lead, up to 1 percent zinc, 0.5 percent each of iron and silica and lesser quantities of sulfur and arsenic.

Theoretical flue-gas rates vary with the size of the furnace from 6,000 to 14,000 scfm, but is usually diluted to several times this flow rate by air entering at the top of the furnace.

The flue gases, before dilution and combustion, may contain 25 to 50 percent carbon monoxide, significant amounts of carbon dioxide and nitrogen. They also contain dusts and fumes from chemical reactions as they become entrained in the air from the tuyeres as it sweeps through the charge. The fumes include cadmium, lead, and zinc oxides.

Table 28.1 contains some reported emission rates for lead blast furnaces. Gas flow rate and temperature values are after air dilution and cooling.

Table 28.1 LEAD BLAST FURNACES

CAPACITIES, EMISSION RATES AND WASTE GAS TEMPERATURES

Plant	Estimated Lead Production Capacity (tons/year)	Waste Gas Temperature (°F)	Waste Gas Flow Rate (scfm)	Dust Recovery (tons/day)
1.	76,000	400	8,500	12
2.	122,000	450	11,100	9.7
3.	198,000	350	26,200	---
4.	120,000	300	23,300	---
5.	91,000	350	20,400	---
6.	42,000	300	--	26

Blast furnaces (Figure 28.1) have rectangular horizontal cross-sections. There are tuyeres in each side, and above these the two long sides slope outwards for a third of the shaft heights. In the upper two-thirds of the shaft, the outward slope is less. Shaft sides and ends are water-cooled steel panels.

The flue gas ducts and charge openings are at the top of the furnace shaft. Below the hearth is a crucible or, in newer furnaces, a trough, sloped toward one end where liquids from the furnace flow continuously to an external settler-separator. Hearth widths range from 4.5 to 6.0 feet and lengths from 15 to 28 feet. The furnace charge is 600 to 1,200 tons/day for hearth areas from 80 to 150 sq. ft.

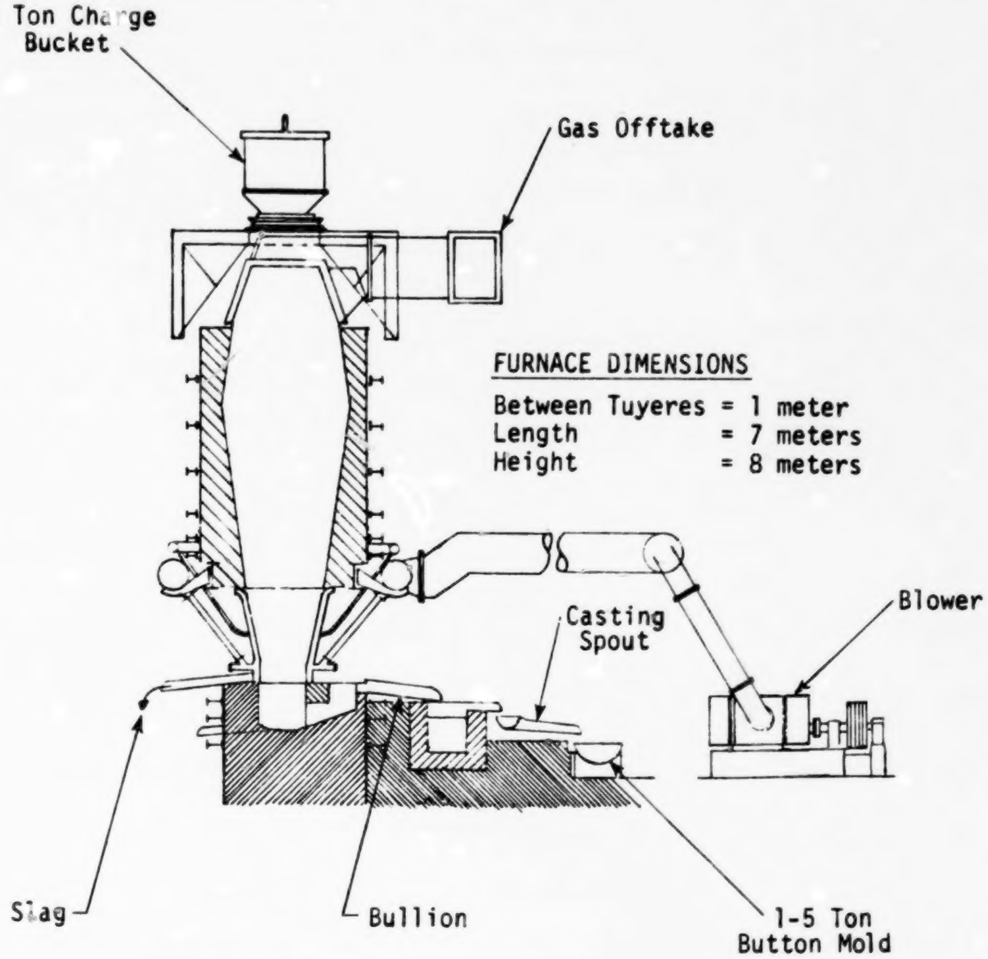

5 Ton Charge Bucket
Gas Offtake
FURNACE DIMENSIONS
Between Tuyeres = 1 meter
Length = 7 meters
Height = 8 meters
Casting Spout
Blower
Slag
Bullion
1-5 Ton Button Mold

FIGURE 28.1 LEAD BLAST FURNACE

28.1.1 Lead refining is the process of recovery of valuable by-products from blast furnace lead and the removal of impurities. Molten lead is first treated in drossing kettles for copper removal. Cooling causes the copper to separate and rise to the surface as a dross. The dross is skimmed off and is smelted in the dross reverberatory furnace. A continuous softening process removes arsenic and antimony through oxidation. The skim may be treated in an electric furnace to produce an arsenical-antimonial lead known as hard-lead. Gold and silver are removed by the addition of zinc metal. The zinc amalgam forms a dross on the surface which is removed. Gold and silver are extracted from the skim by cupellation and retorting. The residual zinc in lead is removed by vacuum distillation. Addition of sodium hydroxide, or caustic soda, removes the last traces of impurities and the final product, corroding lead, is cast out for marketing.

28.1.2 Other smelter operations include dross reverberatory furnaces, cadmium roasters, slag fuming-furnaces and deleading kilns.

A natural gas-fired dross reverberatory furnace separates the remaining lead in the dross skim, matte and speiss from the blast furnace at temperatures of 1,400 to 1,800°F. The lead is sent to the refinery, the matte and speiss to the copper smelter.

The off gases consist mainly of combustion products and average less than 0.05 percent sulfur dioxide, except for short time periods when sulfur is added to the furnace charge when it may go as high as 0.2 percent. Off gas flow rates are relatively low, 1,000 to 3,000 scfm; only sufficient draft is provided to remove the smoke and fumes and still allow as much heat retention as possible over the hearth. Flue dust recovery averages 0.75 tons/day at one plant which is believed to be primarily metal oxides. The speiss and matte compositions are not believed to be altered significantly.

Other lead smelter operations emission data and operating conditions are presented in Table 28.2

Table 28.2 AUXILIARY LEAD SMELTER OPERATIONS, EMISSIONS AND OPERATING CONDITIONS

Operation	Lead Production Capacity (tons/year)	Waste Gas Temperature (°F)	Waste Gas Flow Rate (scfm)	Dust recovered (tons/day)
Plant 1	76,000			
Dross reverb		1,700	1,100	
Plant 2	122,000			
Dross reverb		1,400	8,500	
Slag fuming		600	59.3	67
Plant 3				
Slag fuming		2,200	9,000	
Plant 4	91,000			
Dross reverb		1,700		
Slag fuming		600	19,700	100
Deleading kiln		2,500	4,000	11
Plant 5	42,000			
Dross reverb		1,650	6,000	0.75
Slag fuming		2,200	50,000	[illegible]0
Deleading kiln		1,500		10

These operations are auxiliary to the primary lead smelting process and even though they constitute a significant portion of lead plant operations, they are not fully treated here.

28.2 Process Control Operation

The basic chemical reactions define the important process variables and can readily be identified as the coke and lead content of the charge and the air (oxygen) flow rate. Temperature control plays an important but less critical part than in sintering. In order to reduce lead oxide, 1,100 to 1,300°F is required but temperatures may go higher in portions of the furnace and cause some distillation and carry-over of lead and zinc oxides. Sinter, coke, flux and other dust carry-overs are governed by size distribution and air flow rates, especially during the initial part of the blasting cycle. Good air flow rate control is also important for the production of the reducing agent, carbon monoxide.

The flue gases are collected in a hood and duct system where the carbon monoxide is burned by excess air to carbon dioxide. The volumes of dilution air are large enough to also cool the gas. Further cooling is accomplished by quenching with water. The diluted and conditioned gas is ready for particulate removal by either filtration or precipitation. The clear flue gas is vented through a stack.

28.3 Enforcement Procedure

The objectives of lead blast furnace operation inspection are to determine sulfur dioxide and particulate emission levels from the reduction operation and to evaluate the pollutant emission potential of this operation for varying production rates and operating conditions. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both blast furnace and blast furnace emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels, blast furnace feed weight rates, furnace, and furnace emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

Prior to physical inspection of a lead blast furnace, the enforcement official should obtain specific information regarding the number of location of blast furnaces. The enforcement official should compare the feed weight rate that is indicated on the operator's log during his visit with what is considered normal operation for this particular furnace. This will help establish whether the furnace is being overburdened because of increased production or whether a light load has been charged to the furnace because of the inspector's visit. The most important process variable with a lead blast furnace is the process weight rate, which is the sum of ore, fluxes, concentrates, coke and coke breeze charged to the furnace. The enforcement official should also record the sulfur content of the sinter and of the furnace products. Calculate sulfur emissions from these data.

The enforcement official should examine the air pollution collection hood at the blast furnace to see whether the inspiration volume is adequate to encompass the entire plume during the heaviest particulate emissions. Additional particulate matter may emanate during the slagging and tapping operations. Plants will generally have hoods to capture the particulate from these operations.

INSPECTORS WORKSHEET

FOR LEAD BLAST FURNACE

GENERAL

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

OPERATING VARIABLES

Blast Furnace Feed Rate,__________lb/hr

Sulfur Content of Feed Ore________%

No. of Blast Furnaces__________Capacity of Blast Furnaces, total______tons/day

Sulfur Content of Slag________%

Exhaust gas Flow Rate__________ scfm, _____________ scfm, etc.
(Furnace 1) (Furnace 2)

Type of Control Device______________________________________

Efficiency of Control Device__________%

Inlet Temperature__________°F

Pressure Drop Across Control Device__________in. H_2O

Spark Rate__________spm

No. of Dead Sections__________

EMISSION TESTS

Particulates__________lb/hr

SO_2__________lb/hr, expressed as S__________lb/hr

Tested by______________________________Dated______________

VISUAL OBSERVATIONS

Capture Efficiency______________________________________

____

Ducts____

____

DIAGRAM OF EXHAUST GAS FLOWS

NOTE: For comparison with regulations, total smelter emissions may include sinter plant and reverberatory operations as well as the blast furnaces.

Time In___________

Time Out___________

There is little telltale evidence on a lead blast furnace that would indicate any upset condition has occurred. Occasionally a crust may form over the hot metal and below the cold ore. A slip may occur when the crust finally breaks and drops into the hot pool, resulting in a heavy particulate emission. The enforcement official should observe the air pollution control system during a slip if possible, and note whether the abatement facility is capable of handling the heavy emissions.

Compare calculated sulfur emissions to applicable regulations. If the calculated value exceeds limits, a stack test should be conducted to verify the calculation estimate.

On the basis of stack opacity and/or visible particulate losses from the building, due to inadequate process ventilation, there may be cause for issuing a citation or requiring more definitive tests to determine compliance.

29. ORE REFINING - REVERBERATORY

This is a major potential particulate emission and minor sulfur emission process. Particulate emissions are mainly a function of the adequacy of the control system.

29.1 Process Description

The reverberatory furnace is a high temperature separation process unit where the high lead content of dross skim is separated as lead bullion from the copper matte and slag and, on occasion, nickel bearing material.

The reverberatory furnace is a refractory lined vessel that radiates heat from its burner flame, roof and walls onto the dross charge. Figure 29.1 is a graphical depiction of a representative dross reverberatory

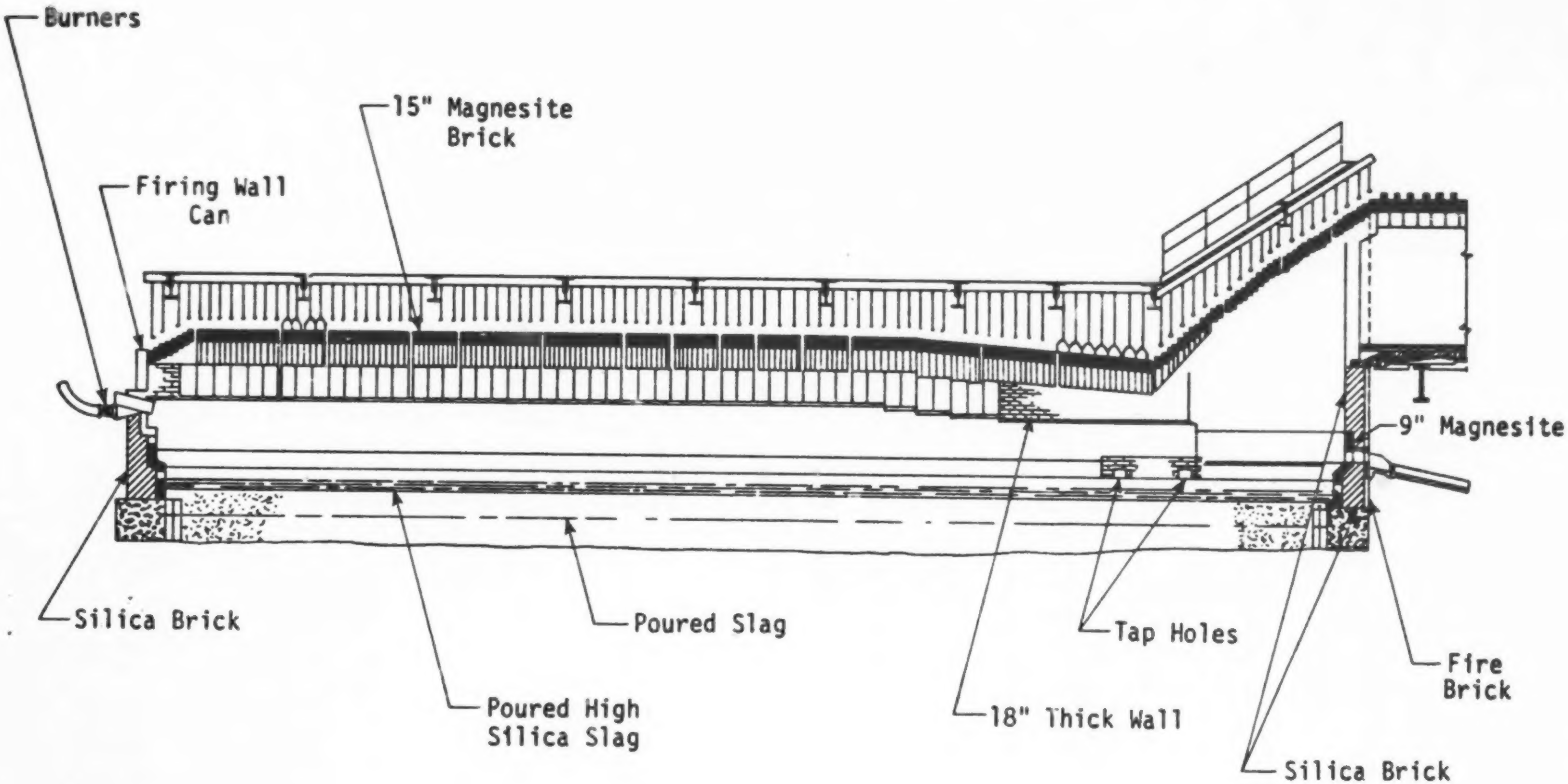

Burners
15" Magnesite Brick
Firing Wall Can
9" Magnesite
Silica Brick
Poured Slag
Tap Holes
Fire Brick
Poured High Silica Slag
18" Thick Wall
Silica Brick

FIGURE 29.1 LEAD REVERBERATORY FURNACE

furnace. Fuel, usually natural gas or fuel oil, and combustion air are introduced into the furnace where the combustion occurs directly above the molten bath; the walls and roof receive radiant heat from the hot combustion products and, in turn, reradiate this heat to the surface of the charge. The process temperature is normally between 1,700 and 1,800°F.

The feed to the furnace may include the following components: dross, soda ash, coke breeze, coal, sawdust, sulfur, ores, and silica. Lead bullion from the blast furnace is sometimes included in the charge as an additional step in the refinery operation. The reverberatory products consist primarily of lead, copper matte, slag, and possibly nickel matte. Tables 29.1 and 29.2 contain some typical reverberatory charge and product weight rates and compositions.

The off gases consist mainly of combustion products and normally average less than one percent sulfur dioxide which may be higher for short periods when sulfur is added to the furnace charge. Off gas flow rates are relatively low, 1,100 to 8,500 scfm, because only sufficient draft is provided to remove the smoke and fumes and still allow as much heat retention as possible over the hearth. Table 29.3 is a listing of some dross reverberatory emission data and operating conditions.

29.2 Process Control Operations

The basic process parameter is temperature, which must be sufficiently high to permit liquefaction of the charge and phase-separation of the liquid lead bullion from by-products that float on top of the molten bath. The method of temperature control is fuel rate adjustment.

The off gases are essentially combustion by-products of either natural gas or fuel oil, slight quantity of excess air, less than one percent

Table 29.1

TYPICAL ANALYSES OF DROSS REVERBERATORY FEED AT ONE LEAD PLANT

Material (%)	Reverb Bullion	Copper Matte	Ni Matte	Dross	Lead
Pb	-	15	35	60	-
Cu	1.4	60	35	13	0.010
S	-	20	-	4.5	-
Ni	-	-	15	3	-
Insol	-	-	-	3	0.004
FeO	-	-	-	1.5	-
Zn	-	-	-	4.3	0.001
Co	-	-	-	0.5	-
Cd	-	-	-	-	0.0000
Bi	-	-	-	-	0.0000
Ag	-	-	-	-	0.031

Table 29.2

TYPICAL REVERBERATORY FEED AND PRODUCT WEIGHT RATES AND COMPOSITIONS AT ONE LEAD PLANT

Weekly Summary of Reverberatory Operations

Material Charged	Tons	% of Charge
Dross	835	92
Soda Ash	45	5
Coke Breeze	16	2
Silica sand	10	1
Material Tapped		
Lead Bullion	590	65
Copper Matte	164	18
Slag	81	9
Ni bearing material	10	1

Table 29.3

LEAD DROSS REVERBERATORY EMISSION DATA AND OPERATING CONDITIONS

Plant	Lead Production Capacity (tons/yr)	Waste Gas Temperature (°F)	Waste Gas Flow Rate (scfm)	Waste Gas Sulfur Dioxide (%)	Dust Recovered (tons/day)
1	76,000	1,700	1,100	0.99	-
2	122,000	1,400	8,500	0.02	-
3	91,000	1,700	-	neg.	-
4	42,000	1,650	6,000	0.52	0.75

sulfur dioxide, and some entrained dusts and fumes. The fumes are believed to be primarily metal oxides.

The off gases are collected in a hood and duct system and may be cooled to about 150 to 300°F by heat exchangers, air dilution, or water spray, before treatment in baghouses. The reverberatory off gases may be combined with other process off gases before particulate removal.

29.3 Enforcement Procedure

The objectives of dross reverberatory furnace operation inspection are to determine sulfur dioxide and particulate emission levels from the furnace operation and to evaluate the pollutant emission potential of this operation for varying production rates and operating conditions. In order to accomplish the above objectives, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,

4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both furnace and furnace emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels, furnace feed weight rates, furnace, and furnace emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

Obtain sulfur content data on both feed and product. Calculate possible sulfur emissions. This could be verified using indicator tubes (Part VII). If these estimates indicate that emissions exceed allowable limits, definitive stack testing and/or a compliance program are indicated.

On the basis of stack opacity and/or visible particulate losses from the building, due to inadequate process ventilation, there may be cause for issuing a citation or requiring more definitive tests to determine compliance.

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PART V

ZINC SMELTING

Zinc is a strategic and critical material and, as such, is one of the government stockpiled metals. The zinc industry is one of the primary metallurgical industries and ranks fourth in production of tonnage after steel, aluminum and copper.

The United States is the world leader in both metal production and consumption. Consumption patterns, both usage and temporal trends, are given in Table V-1 below.

Table V-1 UNITED STATES ZINC CONSUMPTIONS

	Total Consumption, percent			
	1940	1950	1960	1968
Galvanizing	40	46	43	36
Brass	32	14	11	12
Castings	16	30	39	42
Rolled Zinc	8	7	4	4
Other	4	3	3	6
	100	100	100	100
Total Consumption, Short Tons	719,000	967,100	877,900	1,333,700

Table V-2 presents the 1968 United States zinc plants and their salient process identification.

The United States relies on zinc metal supply from domestic primary and secondary plants, imports of metal and its concentrate, and industry

TABLE V-2

SURVEY OF UNITED STATES LEAD AND ZINC PRODUCTION IN 1968

ZINC PLANTS

Country and Company Name	Name/ Location of Plant	Year First Operated	Type of Plant	Type of Roast/Sinter Plant	H_2SO_4 (100%) Annual Capacity	Zinc Slag/ or Residue Treatment	Zinc Metal Production (1968) Annual Capacity	Actual Production < 99.99% Zn	Actual Production > 99.99% Zn	By-Products
American Smelting and Refining Co.	Amarillo, Texas	1923	Horizontal Retort	Ropp/Dwight Lloyd - Down Draft		Direct Smelting	47,600	41,300		Cd Fume
" "	Corpus Christi, Texas	1941	Electrolytic	Flash Roaster	74,500	Direct Smelting	97,975		76,840	Cd
American Zinc Company	Dumas, Texas	1940	Horizontal Retort	Ropp/Dwight Lloyd - Down Draft		Treated Elsewhere	52,980	51,260		
" " "	Monsanto, Illinois	1941	Electrolytic	Fluid Bed		Treated Elsewhere	76,200	19,050	48,270	
Anaconda Company	Great Falls/ Anaconda, Montana	1915	Electrolytic	Fluid Bed/Wedge		Treated Elsewhere	228,600	70,125	70,260	Cd, Cu, In, Pb
Bunker Hill Co.	Bunker Hill, Idaho	1928	Electrolytic	Flash Roaster	215,230	Direct Smelting	95,890		93,390	Cd
Eagle Picher Industries Inc.	Henryetta, Oklahoma	1916	Horizontal Retort/ Waelz	Fluid Bed		Leaching	36,285	25,850		
" "	Galena, Kansas	1954	Roasting Only	Dwight Lloyd - Up Draft	136,075	Leaching	90,720 Zn Nodules			Cd
Matthiessen & Hegeler Zinc Co.	La Salle, Illinois	1858	Horizontal Retort/ Waelz	Dwight Lloyd - Down Draft/Wedge	69,855	Waelz	29,030			Au, Ag, Cd, Pb Se
" "	Meadowbrook, W. Virginia	1911	Vertical Retort	Fluid Bed	272,155	Not Treated	40,825	34,015		
National Zinc Co.	Bartlesville, Oklahoma	1907	Horizontal Retort	Fluid Bed/ Dwight Lloyd - Down Draft	72,850	Magnetic Separation/ Treated Elsewhere	56,955	43,375		Cd
New Jersey Zinc Co.	Palmerton, Pennsylvania	1899	Vertical Retort	Flash Roaster	147,870	Direct Smelting	107,050	45,360	61,505	Cd, In-Pb
" "	Depue, Illinois	1906	Vertical Retort	Fluid Column	362,875	Direct Smelting	63,505	25,215	26,856	In-Pb
St. Joseph Lead Co.	Monaca, Pennsylvania	1938	Electrolytic	Nich.-Herr./Fluid Bed/Dwight Lloyd - Down Draft	281,435	Gravity	181,435	141,520	45,360	Cd, Hg

and government stocks. Of the 1968 consumption, 529,400 tons, or about 40 percent, were produced domestically.

Zinc is a bluish-white metal highly valued for its corrosion resistivity. It is used extensively to galvanize iron and steel products against corrosion. Zinc produced from newly mined ores is termed primary, or virgin zinc, and when it is produced from scrap or residue it is termed secondary, redistilled, or remelt zinc. Primary zinc may be referred to as electrolytic or distilled zinc according to the reduction process used. The final product may be in the oxide form as a powder or in the metal form cast into slabs, usually of 55 pounds. Slab zinc is produced in five standard grades ranging from 98.3 to more than 99.99 percent zinc with certain limits on maximum impurity contents.

The most abundant zinc ore is the sulfide, called "blende", but a composite form of oxides, silicates and other, is also significant. Zinc ores also contain varying amounts of other valuable and recoverable materials, including cadmium, copper, fluorspar, gallium, germanium, gold, indium, lead, manganese, silver, sulfur, and thallium. Other commercially significant sources of zinc include lead ores where zinc is found as a by- or co-product. Zinc is recovered from ore by a combination of pyrometallurgical processes, such as roasting and distillation, or an electrolytic process in lieu of distillation.

Significant industrial uses of zinc include transportation, construction, electrical equipment and supplies, pigments and compounds and others.

Demand for primary zinc is expected to increase to, and range from about, a low of two million to a high of four million tons by the year 2000. The corresponding growth rates for the possible zinc demand are between one and three percent per annum.

The nonmetallic zinc by-products, such as concentrate tailings, are valued by such diverse industries as highway, railroad and agriculture.

Primary zinc production is a sequence of physical-chemical processes that involve the mining and concentrating of the naturally occurring zinc mineral, mostly as sulfide, the preparatory steps that are necessary for reducing zinc to the metal form, the reduction process itself (either electrolytic or pyrometallurgical), and the subsequent zinc purification. Figure V-1 is a simplified process flow diagram of a zinc plant and Tables V-3 and V-4 list plant emissions and products.

Table V-3

DUST-IN OFF GAS RATES FOR SOME PRIMARY ZINC PLANT OPERATIONS

Process Equipment	Feed Capacity (tons/day)	Dust-in Off Gas (% of feed)	Dust-in Off Gas (tons/day)
1. Roasters			
Multihearth	50 to 120	5 to 15	2.5 to 18
Ropp	40 to 50	5	2.0 to 2.5
Fluid Bed (2) (Door Oliver)	240 to 350	75 to 85	180 to 300
Suspension	120 to 350	50	60 to 175
Fluid Column	225	17 to 18	38 to 40
2. Sinter Machines			
Plant 1	240 to 300	5	12 to 15
Plant 2	400 to 450	5 to 7	20 to 32
Plant 3	550 to 600	5 to 10	28 to 60

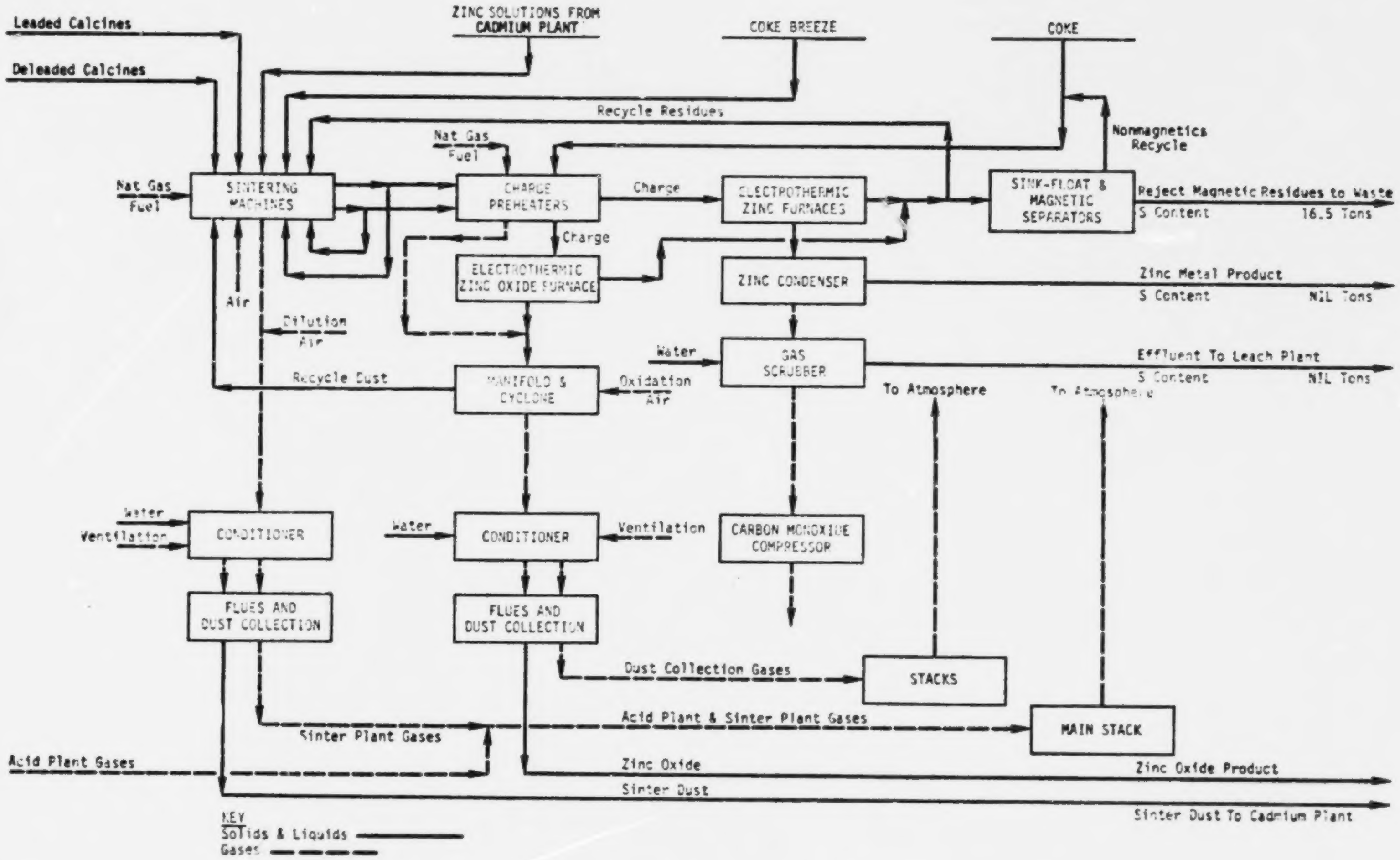
Leaded Calcines
Deleaded Calcines
ZINC SOLUTIONS FROM CADMIUM PLANT
COKE BREEZE
COKE
Recycle Residues
Nonmagnetics Recycle
Nat Gas Fuel
SINTERING MACHINES
Nat Gas Fuel
CHARGE PREHEATERS
Charge
ELECTROTHERMIC ZINC FURNACES
SINK-FLOAT & MAGNETIC SEPARATORS
Reject Magnetic Residues to Waste
S Content 16.5 Tons
Charge
ELECTROTHERMIC ZINC OXIDE FURNACE
ZINC CONDENSER
Zinc Metal Product
S Content NIL Tons
Air
Dilution Air
Water
GAS SCRUBBER
Effluent To Leach Plant
S Content NIL Tons
Recycle Dust
MANIFOLD & CYCLONE
Oxidation Air
To Atmosphere
To Atmosphere
Water
Ventilation
CONDITIONER
Water
CONDITIONER
Ventilation
CARBON MONOXIDE COMPRESSOR
FLUES AND DUST COLLECTION
FLUES AND DUST COLLECTION
Dust Collection Gases
STACKS
Acid Plant & Sinter Plant Gases
MAIN STACK
Sinter Plant Gases
Acid Plant Gases
Zinc Oxide
Zinc Oxide Product
Sinter Dust
Sinter Dust To Cadmium Plant
KEY
Solids & Liquids
Gases

FIGURE V-1 ZINC PLANT FLOW DIAGRAM

Table V-4

PRINCIPAL MATERIALS OF ZINC PRODUCTION AND THEIR ESTIMATED RELATIVE QUANTITIES

Material	Weight
Zinc Ore	100
Gangue	60 to 70
Zinc Concentrate	10 to 15
Tailings	15 to 30
Retort Furnace Residue	5 to 10
Zinc Metal	5 to 6
Coke and Coal	4 to 5
Fluxes and Additives	4 to 5
Other	4 to 5

This section on zinc smelting, is divided into five chapters (Chapters 30 through 34): material handling, concentrate drying, concentrate roasting, sintering, and zinc metal production. Each chapter is subdivided into three parts, namely process description, process control operation and enforcement procedure. This system of subdivision serves as a structure that incorporates basic process and emission control descriptions and operating principles that serve as a foundation for effective monitoring and enforcement.

30. MATERIAL HANDLING

The possible emissions will be particulates. Fugitive dust regulations will govern.

30.1 Process Description

Material handling is an important aspect of zinc production in terms of tonnage of material. Zinc production is the process of separating mechanically and chemically 4 to 5 pounds of zinc from about 100 pounds of mine ore.

Most ore is mined underground and then transported to the surface. The first and most substantial bulk reduction, ore concentration, normally occurs here. Concentrating consists of separating the desirable mineral constituents in an ore from the unwanted impurities by various mechanical processes. Ore size is reduced by crushing and wet grinding. Size separation is accomplished by vibrating or trommel screens and classifiers to give properly sized feed. Heavy-medium cones, jigs and tables separate the zinc minerals from a low specific gravity gangue. Conveyors transport the ore to large bins for blending and storing. The ore is next pumped as an aqueous slurry to flotation cells where it is conditioned by additives. Large propellers stir the solution and the zinc-bearing minerals separate and float to the surface where they are skimmed off. The unprofitable part of the slurry, called tailings, may be treated in cyclone type separators to remove fines from the sand.

Once separated, the metal concentrates are thickened in settling tanks and the slurry is fed to vacuum drum filters which reduce the moisture content to a small percent. At completion of the concentration process, the zinc content has been upgraded to about 55 to 60 percent. Thermal drying may be used to further reduce the moisture content of the concentrates.

The concentrates are transported to a storage site and stored in bins. Usually, the first step of zinc smelting is the conversion of zinc sulfides to zinc oxide by roasting. The sulfur is converted to sulfur dioxide and is driven off in the off gases. The reduction of zinc ores and concentrates to zinc is accomplished either by electrolytic deposition from a solution or by retorting.

The low sulfur calcine is weighed in hoppers and introduced into tanks where it is leached with dilute sulfuric acid solution. Most metals, among them zinc, copper, cadmium, arsenic, antimony, cobalt and nickel, enter the solution as sulfates. Insolubles suspended in this mixture include lead, silver, gold, iron, silica and calcium which are removed by filtration. Most of the soluble metals are removed from solution by selective precipitation and filtration until the zinc sulfate solution is ready for electrolysis. Zinc is finally electrodeposited on aluminum cathodes. The high purity zinc is removed from the cathodes and the sulfuric acid (generated during electrolysis) leaching solution is recycled.

Pyrometallurgical extraction employs different processes and reduction principles. The preparation of calcined zinc oxide for pyro-chemical reduction involves agglomeration, either by sintering or by nodulizing and blending with coke, fluxes and additives. The blended feed is ready for retorting, in some cases, after briquetting. Zinc is finally reduced to zinc metal in retort furnaces and the distilled metal is recovered from the effluent by condensation. The liquid zinc may be cast into slabs or further refined by distillation. The magnetic content of the retort residue may be recovered and further processed, the rest goes to waste.

The material handling equipment may include such primary means of transportation as rail, trucks, ships, barges and pipelines. The secondary, or more highly specialized equipment includes conveyors, overhead cranes, clamshell loaders and cars. Modes of material storage include: piles, bins, hoppers, kettles, settling tanks and ponds. Material handling process equipment include crushers, grinders, vibrating screens, clarifiers, heavy-medium cones, jigs, tables, flotation cells, vacuum filters, electrolytic cells, leaching tanks, roasters, sintering machines, nodulizers, retort furnaces. Table 30.1 summarizes the major process and material flows involved in primary zinc production. Figure 30.1 depicts principal retort process emission points.

Of primary concern in material handling is the containment and control of fugitive dusts which are generated when sufficiently fine size material is exposed to moving air. Such material may be stationary or in transit. Most dusts become airborne during periods of loading and unloading at points of transfer.

30.2 Process Control Operation

There are two effective and widespread methods of dust control: water or other chemical sprays and physical capture and confinement by such means as hoods and other enclosures.

Some of the most important variables affecting dust emission into air are particle size and density, the relative velocity between particle and air, and the size of the surface area exposed to air per unit volume of dust. Total emission control includes, in the final analysis, the manipulation of all the variables affecting emission rates.

It is relatively simple to identify the major material handling process variables, namely mass flow rates, composition, size distribution, plant physical layout and material flow paths at an individual plant.

PROCESS AND MATERIAL FLOW

PRIMARY ZINC PRODUCTION

	Process	Feed	Product	By-Products and Waste
1.	Mining	-------	raw, coarse ore	
2.	Mechanical separation	raw, coarse ore	concentrated ore	gangue (light solids)
3.	Flotation concentration	concentrated ore	wet zinc concentrate	tailings (slurry)
4.	Concentrate drying	wet concentrate, fuel, air	dry zinc concentrate	gases, dusts, fumes
5.	Concentrate roasting	concentrate, fuel, air	calcined ore	gases, dusts, fumes
6.	Metal extraction	-------	zinc metal	-------
6.1	Electrolytic extraction	-------	zinc metal	-------
6.1.1	Leaching	calcined ore, dilute sulfuric acid	metal sulfate solution	-------
6.1.2	Filtering	metal sulfate solution	solubles (in solution)	insolubles (lead, gold, silver, silica, iron, calcium)
6.1.3	Precipitations, filtrations	solubles (in solution)	zinc sulfate solution	solids (copper, cadmium, cobalt, nickel, antimony, arsenic)
6.1.4	Electrolysis	zinc sulfate solution	zinc metal, 99.99% pure	electrolytic solution (to leaching)
6.2	Pyrometallurgical extraction			
6.2.1	Sintering			
6.2.1.1	Mixing	calcined ore, coke, coal, dusts	sinter feed mix	
6.2.1.2	Sintering	feed mix, air	sinter	gases, dusts, fumes

Table 30.1 (Cont'd)

PROCESS AND MATERIAL FLOW

PRIMARY ZINC PRODUCTION

	Process	Feed	Product	By-Products and Waste
6.2.2	Nodulizing	calcined ore	calcined nodules	gases, dusts, fumes
7.	Mixing/Briquetting	sinter or nodules, coke, coal, fluxes	retort feed mix	----------
8.	Retorting	feed mix	effluent (zinc fumes)	residue
9.	Condensation	retort effluent	liquid zinc	gases, dusts, fumes
10.	Refining	zinc from retorting	zinc, 99.995% pure	residue

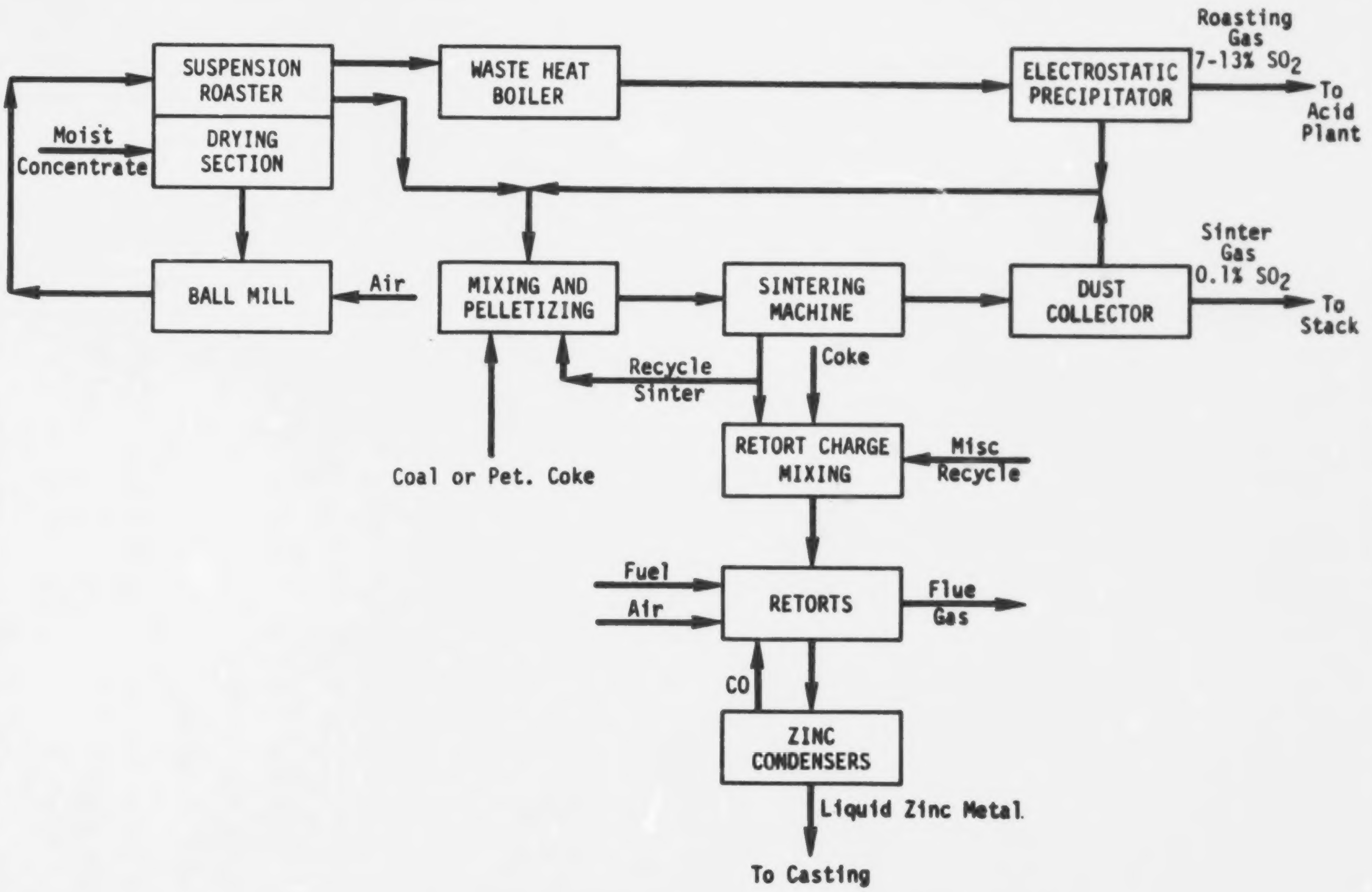
SUSPENSION ROASTER
DRYING SECTION
Moist Concentrate
BALL MILL
Air
WASTE HEAT BOILER
ELECTROSTATIC PRECIPITATOR
Roasting Gas 7-13% SO_2
To Acid Plant
MIXING AND PELLETIZING
Coal or Pet. Coke
Recycle Sinter
SINTERING MACHINE
Coke
DUST COLLECTOR
Sinter Gas 0.1% SO_2
To Stack
RETORT CHARGE MIXING
Misc Recycle
Fuel
Air
RETORTS
Flue Gas
CO
ZINC CONDENSERS
Liquid Zinc Metal
To Casting

FIGURE 30.1 ZINC RETORT PLANT EMISSION SOURCE DIAGRAM

30.3 Enforcement Procedure

The enforcement official should make a subjective type evaluation of the material handling system for the concentrate building. It is unlikely that any of the ore will be entrained by air and present a fugitive dust problem. The enforcement official should check the transfer points and the enclosed system of the storage hoppers.

The enforcement official should make note of the amount of material processed through the concentrate building for future comparisons. No atmospheric testing needs to be done at this particular process during the enforcement official's inspection visit.

If fugitive dust violations are apparent, take appropriate action.

31. CONCENTRATE DRYING

The possible emissions will be particulates. Likelihood of emissions is remote from the wet part of the system. The dryer can be a major particulate source if control equipment is not functioning properly.

31.1 Process Description

The preparation of the zinc concentrate is usually done wet by gravity or flotation methods. Flotation is usually used to eliminate as much of the lead as possible. The concentrated zinc ore usually contains about sixty percent zinc.

Depending on the type of sintering and/or roasting operation that may accompany a zinc plant, some of the raw zinc ore may be dried. The drying process takes place in direct-fired rotary dryers. Concentrate entering the dryer contains about 11 percent moisture and leaves at about 3 percent moisture. Below about 3 percent moisture, the concentrate becomes quite dusty. It is stored in a concentrate silo for future processing in the flash roaster or sintering plant.

INSPECTORS WORKSHEET

FOR RECEIVING, STORING AND HANDLING OF RAW MATERIALS

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

Type of Plant____

Capacity of Plant____

Source Location	Type Material	Wind Direction Wind Speed (mph)	Plume Description	Preventive Measures
Sample Concentrate belt unloading	Ore Concentrate	SW/10	slight visible dust	Water spray
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				

Dust emissions occur as the hot air passes over the moving bed of concentrate. Most plants will have some type of particulate abatement equipment at the dryer as dust caught in the air pollution device can easily be recirculated into the storage bin for further use. Cyclones and low-to-medium energy scrubbers are likely to be used to remove the particulate matter from the exhaust gas stream. Cyclones operate on a dry principle and could remove much of the large particles for reuse directly into the flash roaster with no further processing. Particulates caught in the scrubbers will need to be dried before reuse in the roasters or sintering plants. Since the specific purpose of this dryer is to reduce the moisture content of the ore, a water plume will be noted at the stack outlet. Not all zinc plants will have an ore drying operation; virtually no sulfur dioxide is driven off during this process.

31.2 Process Control Operation

Emission to the atmosphere from this process will depend on the adequacy of the air pollution control system. There is likely to be a corporate motivation to include air pollution control systems on this process since the raw ore can easily be reused at another stage in the zinc reduction process. Pollution control efficiencies for this type of system will require about 90 percent removal efficiency. This can be accomplished with the use of low energy scrubbers and multicyclone devices. Operating factors likely to affect air pollution emissions are process feed rate and product moisture content.

The concentrate drying operation is a continuous one and will normally operate 24 hours per day. Very few operating instruments are likely to be found for this particular process. If any, the gas feed rate and the ore feed rate would be recorded on a daily basis. Analysis of the moisture that is sent to the sintering plant or the flash roaster is critical and would be recorded at the control booth.

31.3 Enforcement Procedure

The enforcement official should obtain data on the process feed rate, moisture contents, and the fuel firing rate for the dryer. This data would be used for future comparisons to determine whether any change in production rate has occurred for this particular plant. The enforcement official should record the operating variables for the air pollution control device. These include the:

1. Gas pressure drop across the scrubber or cyclone,
2. Water flow rate,
3. Air flow rate.

The enforcement official should check the hood capture system used at the tail end of the dryer. Any dust plumes are an indication of a poorly designed unit, clogged ducts, or malfunctioning control equipment. The enforcement official should observe the plume for visible emissions. A water vapor plume will be noted at the stack outlet. The enforcement official should check for any visible plume noticeable beyond the vapor plume. A visible plume would indicate that the control device may not be operating satisfactorily. Reference to allowable emissions and opacity regulations must be made. If opacity of plume downwind of the steam plume is excessive, appropriate action should be taken.

32. CONCENTRATE ROASTING

This is the major point of sulfur emissions in the zinc smelting process. Individual plants may have sulfur recovery units. It is also a possible major source of particulate emissions if control equipment is not functioning properly.

32.1 Process Description

Roasting zinc concentrate is a preparatory step to zinc extraction. It consists of a high temperature exothermic process that converts metal sulfides to metal oxides and fuses the concentrate into a porous mass called calcined oxide. This oxide may require further processing prior to zinc extraction, either by electrolytic or pyrometallurgical methods. If extraction is by pyrometallurgy, further calcining of the oxides is usually necessary.

Fuel combustion is required to initiate the reaction which, if the sulfide concentration is high enough, becomes self-sustaining.

Reaction temperatures vary from plant to plant between 1,200 and 1,900°F depending on the type of roaster, concentrate composition and the specific use of the calcine (see Table 32.1). Roaster calcine size also depends on the same factors and can vary from fine powder to walnut sized chunks.

Differing requirements have resulted in a great diversity of roaster machine forms, the most important of which are the multiple hearth furnace, flash roaster, and fluid bed roaster.

Multiple hearth roasters are some of the oldest and most popular. The roaster consists of a brick lined cylindrical steel shell through which runs a central shaft with two rabble arms attached for each hearth. There may be from four to sixteen hearths in each roaster. The motor driven shaft contains cooling pipes and rotates slowly, about one-half to two revolutions per minute. Seven to nine rakes or rabbles are attached to each arm. Their arrangement is such that the ores introduced into and dried in the upper chamber are gradually moved from the outer edge toward the center and fall through a drop hole onto the first hearth.

Table 32.1 TYPICAL ZINC ROASTING OPERATIONS (1)

Type of Roaster	Operating (°F)	Feed Capacity (tons/day)	Dust-in Off Gas (% of feed)	Off Gas (SO_2%)
Multihearth	1,200-1,350	50-120	5-15	4.5-6.5
Multihearth (2)	1,600-1,650	250	5-15	4.5-6.5
Ropp (3)	1,200	40-50	5	0.7-1.0
Fluid Bed (4) (Dorr-Oliver)	1,640	140-225	70-80	7-8
Fluid Bed (2) (Dorr-Oliver	1,650	240-350	75-85	10-12
Fluid Bed (Lurgi)	1,700	240	50	9-10
Suspension	1,800	120-350	50	8-12
Fluid Column	1,900	225	17-18	11-12

(1) Dead roast except where noted otherwise.

(2) First stage is a partial roast in multihearth, second stage is a dry-feed dead roast in Dorr-Oliver fluid bed.

(3) Partial roast.

(4) Slurry Feed.

The ore then moves across this hearth to a slot near the outer edge and drops to the second hearth. The ore progresses through the furnace in this zig-zag fashion until it drops into a car or conveyor beneath the lowest hearth. There are doors for visual observation, repairs and admission of air for each hearth. Multihearth roaster feed capacities vary between 50 and 250 tons per day.

Suspension, or flash roasting, resembles the burning of powdered coal in furnaces wherein finely ground concentrates are sprayed into a combustion chamber in a stream of combustion air. The reaction usually proceeds without the addition of fuel unless the sulfide content is too low, in which case fuel addition, normally undesired is required. The roaster itself resembles multihearth roasters. It is made up of a refractory-lined cylindrical steel shell. The upper portion contains the combustion chamber and the lower portion two to four hearths, similar to those of the multiple hearth furnace. The feed concentrate is introduced into the lower one or two hearths to dry before final grinding in an auxiliary ball mill. The dried and ground concentrate is then introduced into the combustion chamber. Rotating rabble arms move the material on the hearths. Flash roaster feed capacities vary from 120 to 350 tons per day.

Fluid-bed roasters are continuous operating fluidized concentrate feed combustion chambers. The closely size-regulated, dry, pelletized or slurry feed is introduced to the usually rectangular cross-section reactor. Low pressure air is introduced into a windbox and passes through the perforated bottom which acts as an air distribution plate. The feed is lifted and fluidized. Additional air may be introduced through inlets on each side of the bed. The roasted material overflows into a collection system and the gases go to waste heat boilers for heat recovery and to gas cleaning equipment. Table 32.1 shows some typical roaster capacities and operating conditions.

Agglomeration of the calcined oxide from the roaster is usally required before retorting which may be done by either sintering or nodulizing. Both of these processes involve high temperature fusion and some additional sulfide conversion (see Chapter 33).

The roaster feed is zinc concentrate consisting of 52 to 60 percent zinc, 30 to 33 percent sulfur, 4 to 11 percent iron and lesser quantities of lead, cadmium, copper and other. Franklinite ore requires special processing to recover iron and manganese in addition to zinc. Additional fuel may be required and therefore it may be included in the process weight, depending on the type of fuel and applicable regulations.

The roasting process converts 93 to 97 percent of the sulfur in the concentrate to sulfur dioxide.

The roaster products consist of the calcined oxides and the off gases. Since the solid products' size distribution includes significant portions of fines, a substantial portion of the feed is carried over by the off gases requiring major dust recovery operations. Metal fumes, especially that of cadmium, constitute an appreciable portion of the waste gas particulate carry over.

The volumes of off gases produced range from 5,000 to 6,000 scfm for multiple hearth roasters, 10,000 to 15,000 scfm for suspension roasters and 6,000 to 10,000 scfm for fluid-bed roasters. Sulfur dioxide content of off gases ranges from 4.5 to 6.5 percent for multiple hearth roasters and 7 to 12 percent for suspension and fluid-bed roasters.

Tables 32.1 and 32.2 contain more specific operation information.

32.2 Process Control Operation

The basic chemical reactions define the important process variables, which are: feed composition, feed mass rate, and air flow rate. Roaster configuration and concentrate size distribution also affect particulate emission potential. Operating conditions vary greatly from plant to plant depending on the feed composition, type of roaster and the specific use of the roaster calcine. Process temperature plays an important, but not critical, role in monitoring. It varies between 1,200 and 1,900°F for all plants although the range for a specific roaster is considerably

Table 32.2 ZINC ROASTERS

CAPACITIES, EMISSION RATES AND WASTE GAS TEMPERATURES

Plant	Estimated Zinc Production Capacity (tons/year)	Waste Gas			Sulfur Equivalent of Sulfur Oxide Emission Rate (tons/year)
		Temperature (°F)	Flowrate (scfm)	Dust Recovery (tons/day)	
1	252,000	1,600	94,500	n.a.	159,000
2	88,000	1,600	32,000	n.a.	49,900
3	88,000	1,900	22,200	80	50,100
4	59,000	2,000	16,000	n.a.	33,600
5	92,000	n.a.	23,000	n.a.	52,100
6	44,000	1,200	9,500	n.a.	23,400
7	215,000	--	--	--	124,000
8	53,000	700	123,000	n.a.	27,000
9	56,000	900	166,000	n.a.	26,500

narrower. Higher roasting temperatures distill more cadmium and increase formation of ferrites. Temperature control is usually achieved by air flow rate control. The combination of air flow rate, particulate size distribution and equipment configuration affect the quantity of dust carry over. The composition of the distilled metal fumes is determined primarily by the concentrate composition and the operating temperature.

Roaster off gases require cooling and conditioning before particulate emission control. Emission control is usually accomplished in two stages. The first stage is cooling (normally by dilution) and removal of coarse particulates in cyclones. The secondary stage is a high efficiency control device, such as a filter or precipitator.

32.3 Enforcement Procedure

The objective of the zinc concentrate roasting operation inspection is to establish compliance with sulfur dioxide and particulate emission regulations. In order to accomplish the above objective, the enforcement official needs to determine:

1. Current production levels and operating conditions,
2. Design production levels and operating conditions,
3. Current controlled and uncontrolled particulate and sulfur dioxide emission levels,
4. Efficiency and adequacy of emission control equipment at current and design operating levels.

Both roaster and roaster emission control equipment design capacities and operating conditions can be obtained from design drawings and plans. These data should be obtained from the company representative prior to physical plant inspection. Production levels, roaster feed weight rates, roaster, and roaster emission control equipment operating conditions are monitored by the plant operator and are either recorded in the operator's daily log or are displayed on instrument panels.

All zinc roasters will have a control booth near the roaster for careful monitoring. The enforcement official should have little difficulty assessing the current operating status of the roaster by observing the many recorders, gauges and logs which are normally kept for the roaster.

Of primary importance for the enforcement of air pollution emission regulations is the process weight rate and the sulfur content. With the mass rate and sulfur content of the feed and calcine, a sulfur mass balance can be calculated. From this, SO_2 emissions can be computed. If an acid plant is used to treat the gases, acid production data must be obtained. The calculated SO_2 mass equivalent scrubbed out by the acid plant must be subtracted from the computed emissions based on the mass balance. Compare the net computed emissions with allowable levels in the regulations and take appropriate action if necessary. It should be pointed out that many state regulations restrict sulfur emissions from the entire zinc smelter and not just the zinc roaster. For determining compliance with the regulations, sulfur emissions from each operation must be summed, then compared. Almost 90 percent of the sulfur is removed in the roasting process. If an approximation of compliance is desired, the calculated sulfur emissions from the zinc roaster may be used. Many zinc roasters will have a sulfuric acid plant to treat exhaust gases from the roaster. These plants will monitor SO_2 gases continuously. The enforcement official should note the flow and concentration of the acid plant inlet and outlet gases for subsequent inspections. There should be little deviation (± 20 percent) from visit to visit because of the fixed design of acid facilities.

There is little that can be noted on instrument panels regarding the amount of particulates emitted to the atmosphere. Some plants will have a smoke density meter which may be used to determine relative particulate emissions from one visit to another. The enforcement official should note the operational parameters of the air pollution control devices.

Visible emissions are the simplest means for estimating particulate control equipment performance. The enforcement official should estimate the percent opacity of dust control equipment stack plume and if in excess of allowable limits, take appropriate action. Building openings should also be observed for evidence of escape of inadequately captured process dust and if noted, determine point(s) of origin and require corrective action.

The enforcement official should subjectively analyze the appearance of the zinc roaster and note any leaks, SO_2 odors, and condition of the duct, etc. Finally, some attention should be given to the dust emission from the material handling of the feed ores and calcine to and from the roasting machine.

INSPECTORS WORKSHEET

FOR ZINC ROASTING

GENERAL

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

OPERATING VARIABLES

Roaster Feed Rate____________lb/hr Calcine Product Rate____________lb/hr

Sulfur Content of Feed Ore________%

No. of Roasters_____Capacity of Roaster__________tons/day

Moisture Content of Feed Ore______%

Sulfur Content of Calcine_________%

Exhaust Gas Flow Rate_____________

Type of Control Device____________________________________

Efficiency of Control Device: Part._______%, SO_2_________%

Inlet Temperature____________^oF

Pressure Drop Across Control Device___________in. H_2O

Spark Rate_________spm

No. of Dead Sections___________

EMISSION TESTS

Location of Test Ports____________________________________

Particulates_________lbs/hr

SO_2___________lb/hr, expressed as S_________lb/hr

Tested by______________________Dated________________________

VISUAL OBSERVATIONS

Capture Efficiency____________________________________

Ducts____

SO_2 Odor____

Other____

DIAGRAM OF EXHAUST GASES AND PROCESSES

Time In ____________ Time Out ____________

33. CONCENTRATE SINTERING

This is a major potential particulate emission and minor sulfur emission process. Particulate emissions are mainly a function of the adequacy of the control system.

33.1 Process Description

Sintering is a process that converts remaining metal sulfides to metal oxides. It eliminates residual lead and cadmium and densifies or fuses the roasted calcine to make it suitable for retorting

The feed to the sintering machine consists of a pelletized mixture of roasted calcine and coal, or coke, and sinter dust. The pelletized mixture is fed uniformly across the grates of the sintering machine on top of a shallow returning sinter layer consisting of coarse particles. The feed is ignited as it enters the natural gas-fired ignition box and combustion is sustained by supplying air to the pellets. Combustion gases are removed, usually through sectionalized wind boxes. Just before the discharge end of the machine, the top layer of the sinter bed is shaved off by a rotating scalper. This top layer, from which about 80 percent of the cadmium and 40 percent of the lead may have been eliminated, constitutes the sinter product containing approximately 60 percent zinc, 0.4 percent lead and 0.05 percent cadmium. The lower portion of the bed, not removed by the scalper, is discharged at the end of the machine to a set of crushing rolls and then the coarser material may be separated on a vibrating screen. The oversized particles are returned to the sinter machine while the undersize material is incorporated with the sinter feed mix.

The off gases contain usually less than 1 to 2 percent sulfur dioxide. This represents, depending on the roaster sulfur removal efficiency, only

1 to 5 percent of the sulfur originally present in the feed. In addition to sulfur oxides, the gases contain air, water vapor, carbon dioxide, and traces of other gases. The fumes consist primarily of cadmium, lead, zinc, and arsenic oxides. Other metals and other compounds are also present in lesser quantities. The fumes condense and are collected with the dust.

Some plant capacities, emission rates, and operating conditions are shown in Table 33.1. Table 33.2 summarizes some zinc sintering operations.

Table 33.1 ZINC SINTERING MACHINES CAPACITIES, EMISSION RATES AND WASTE GAS TEMPERATURES

Plant	Estimated Zinc Production Capacity (tons/year)	Waste Gas Temperature (°F)	Waste Gas Flowrate (scfm)	Sulfur Equivalent of Sulfur Oxide Emission (tons/year)
1	88,000	400	23,200	200
2	92,000	200	150,000	60,100
3	215,000	400	58,500	4,400
4	53,000	200	95,000	5,800
5	56,000	300	22,200	7,800

Table 33.2 ZINC SINTERING OPERATIONS

Case	1	2	3
New feed material	calcine	calcine	concentrate
Total charge capacity (tons per day)	240 to 300	400 to 450	550 to 600
Machine size (ft)	3.5 x 45	6 x 97	12 x 168
Fuel added to feed (%)	6 to 7	10 to 11	0 to 2
Total sulfur in new feed (%)	8	2	31
Recycle (% of new feed)	35 to 75	40 to 70	80
Dust-in off gas (% of feed)	5	5 to 7	5 to 10
Off gas SO_2 content (%)	1.5 to 2.0	0.1	1.7 to 2.4

Sintering machines, known as Dwight-Lloyd machines, range in size from 3.5 ft wide x 45 ft long to 12 ft wide x 168 ft long and from 100 to 2,000 square feet of bed area. The loading capacity variation is from 0.75 to 1.75 tons per day/square foot of bed area. Figure 33.1 is a graphical depiction of a sintering machine and process flow. In some machines air is introduced from above and flows through the ore bed on the conveyor and captured in the wind box and duct underneath. These are known as downdraft machines and are most widely used in the zinc industry. In other machines, the air flow is the reverse. These are known as updraft machines. The temperature of the combined exit sinter gases vary from 500 to 700°F which may be cooled by air dilution and water sprays in preparation for gas cleaning. The primary collection means of particulate removal may be by cyclones and settling chambers followed by secondary removal in electrostatic precipitators or baghouses.

33.2 Process Control Operation

The most important process variable is temperature. Temperature control is achieved by limiting the coke and coal content and the sulfur content of the sinter mix. Once oxidation is started it becomes self-sustaining. Air flow regulation provides additional temperature control.

Sulfur dioxide emission is dependent on the sulfur content of the roasted calcine or zinc concentrate. It may be assumed that all of the 1 to 5 percent of the original sulfur content of the zinc concentrate remaining in the roasted calcine is driven off as sulfur dioxide in the sinter off gases.

The sinter crushing and screening operations have enormous particulate emission potential. These operations will be hooded and ducted to a control device.

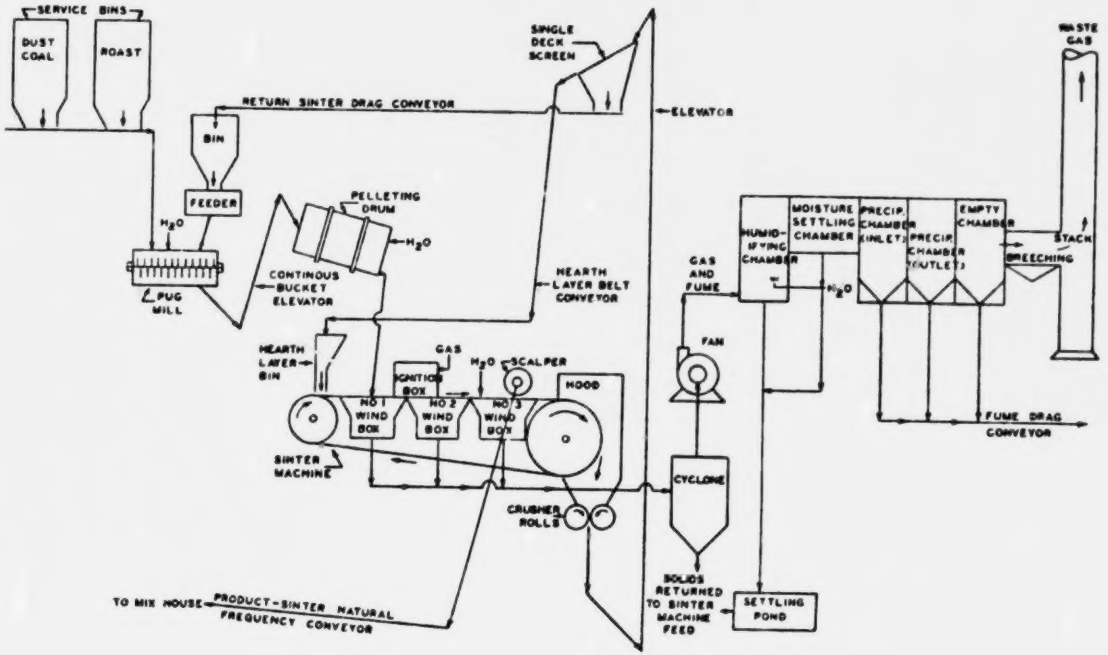
SERVICE BINS
DUST COAL
ROAST
RETURN SINTER DRAG CONVEYOR
BIN
FEEDER
H_2O
PUG MILL
PELLETING DRUM
H_2O
CONTINOUS BUCKET ELEVATOR
SINGLE DECK SCREEN
ELEVATOR
HEARTH LAYER BELT CONVEYOR
HEARTH LAYER BIN
GAS
IGNITION BOX
H_2O
SCALPER
HOOD
NO 1 WIND BOX
NO 2 WIND BOX
NO 3 WIND BOX
SINTER MACHINE
CRUSHER ROLLS
TO MIX HOUSE
PRODUCT-SINTER NATURAL FREQUENCY CONVEYOR
GAS AND FUME
FAN
CYCLONE
SOLIDS RETURNED TO SINTER MACHINE FEED
SETTLING POND
HUMIDIFYING CHAMBER
MOISTURE SETTLING CHAMBER
PRECIP. CHAMBER (INLET)
PRECIP. CHAMBER (OUTLET)
EMPTY CHAMBER
H_2O
STACK
BREECHING
WASTE GAS
FUME DRAG CONVEYOR

FIGURE 33.1 SINTER PLANT FLOW SHEET

Table 33.3 shows some feed capacities, dust-in off gas and dust recovery rates for some zinc plant operations.

Table 33.3 DUST-IN OFF GAS RATES FOR SOME ZINC PLANT OPERATIONS

Sintering Machine	Feed Capacity (tons/day)	Dust-in Off Gas (% of feed)	Dust-in Off Gas (tons/day)
Plant 1	240 to 300	5	12 to 15
Plant 2	400 to 450	5 to 7	20 to 32
Plant 3	550 to 600	5 to 10	28 to 60

Emission rates and concentrations are expected to vary with feed composition, type of equipment used, and operating skill.

33.3 Enforcement Procedure

Sintering plants are traditionally dusty. The enforcement official is likely to find the sintering operation the dirtiest building at a primary zinc manufacturing plant.

The wind box fan operates at a high negative pressure in order to pull combustion air through the bed. Leakage between the bed and the fan will draw in a substantial amount of dilution air and increase the system gas volume. If a precipitator is used, its performance will be degraded when gas volume exceeds the design capacity.

Zinc sinter dust is very abrasive. Ducts can develop holes and the seals between the wind boxes and the bed can deteriorate causing a major maintenance problem at older plants.

The enforcement official must take particular note of the stack opacity for elevated visible dust levels. If noted, one probable cause is dilution air drawn into the system through leaks. The plant inspection should include observation of the system of wind boxes and ducts leading to the dust collector.

INSPECTORS WORKSHEET

FOR ZINC SINTER PLANTS

GENERAL

Plant Id.____

Date of this Inspection____________Date of last Inspection____________

OPERATING VARIABLES

Sinter Machine Feed Rate, including ore, concentrate flux coke, etc.____ ton/hr

Sulfur Content of Feed Ore__________%

Calcine Discharge Rate__________ton/hr

Calcine Sulfur Content__________%

Moisture Content of Feed Ore________%

Temperature of Off Gases________ ^{o}F

Sinter Machine Bed Speed__________ft/hr

Number of Windboxes__________

Exhaust Gas Flow Rate__________scfm

Pressure Drop at Each Windbox; in. H_2O

1	2	3	4	5	6	7	8	9	10

ABATEMENT EQUIPMENT

Type of Unit____

Pressure Drop__________in. H_2O

Spark Rate________spm

Primary Voltage________kv

Water Flow Rate________gpm

VISUAL OBSERVATIONS

Note leaks on sinter machine________________________________

____

Is SO_2 odor present?______Strong, Detectable, Barely detectable

Describe Ductwork___________________________________

____

Maintenance Program_________________________________

____

Develop a diagram indicating gas flow from the sinter machine to atmosphere.

Time In__________

Time Out__________

Good maintenance is a major part of plant operation, so records will likely be available. The precipitator should likewise be inspected for its general condition. Particular note should be made on the adequacy of dust control when dust hoppers are emptied.

Compare calculated emissions to applicable regulations. If the calculated value exceeds limits, a stack test should be conducted to verify the calculation estimate.

On the basis of stack opacity and/or visible particulate losses from the building due to inadquate process ventilation there may be cause for issuing a citation or requiring more definitive tests to determine compliance.

There are not likely very many monitoring instruments for the sintering operation, and at best, the control booth will monitor the pressure drop in each of the wind boxes. Occasionally, a hole may result in the bed and cause excessive particulate generation. The enforcement official should ask how many holes occurred in the sinter bed for the preceding day for subsequent comparisons. The enforcement official should also fill out the Inspector's Work Sheet for this operation.

34. ZINC METAL PRODUCTION

Emissions from the electrolytic process may contain minor amounts of sulfuric acid mist. The pyrometallurgical processes emit particulates. Emission levels are a function of control equipment adequacy.

34.1 Process Description

The reduction of roasted zinc calcine to metallic zinc is accomplished either by electrolytic depostion from a solution or by pyrometallurgical reduction.

34.1.1 Electrolytic extraction - This process consists of dissolving the calcined metal oxides in a sulfuric acid solution and separating the various soluble and insoluble metals from this solution by selective precipitation and filtration until the zinc sulfate solution is ready for electrolytic reduction of sinc. The high purity zinc is removed from the cathodes and the electrolyte (aqueous solution containing the sulfuric acid generated during electrolysis) is recycled to the leaching tanks.

The roasted sulfur-free calcine is weighed in hoppers and apportioned into leach tanks. The dilute sulfuric acid electrolyte, returned from the cell room, is mixed with the calcine in the leaching tank and the ensuing chemical reaction converts the metal oxides to the respective metal sulfates. The soluble metal sulfates, among them zinc, copper, cadmium, arsenic, antimony, cobalt, and nickel are dissolved and go into solution. The insolubles suspended in this aqueous mixture include lead, silver, gold, iron, silica, and calcium. The insolubles are first separated from the solution by filtration. The dewatered residue from the settling tank contains the lead, gold and silver which are sent to the smelter and recovered.

The filtered zinc sulfate solution is piped to an agitator tank and enough zinc dust is added to precipitate the copper. The copper precipitate is removed from solution by filtration. This same process is repeated through several stages. Other metals such as cadmium, cobalt, nickel, antimony, and arsenic are precipitated out of the solution. The residues from the first two filtrations are put into water to form a slurry which is leached with electrolyte from the cell room and the copper is filtered out. Zinc dust is added to the remaining solution and the cadmium is removed by filtration. The spongy cadmium product is refined by dissolving it in a cadmium cell electrolyte from which the cadmium metal is recovered by electrolysis, melted, and cast into various shapes.

The remaining zinc sulfate solution is treated in a cell where the zinc is removed by electrolysis and deposited on aluminum cathodes. The spent electrolyte is returned to the leaching tanks for reuse, and the zinc is stripped from the cathodes and sent to the primary melting furnaces. The 99.99+ percent pure zinc metal is tapped from the furnaces and cast into blocks.

34.1.2 Pyrometallurgical zinc reduction - This process is a high-temperature carbon monoxide reduction process.

The reduction temperature is between 1,800 and 2,400°F and the pyroreduction may be done in horizontal or vertical retorts, or in open or submerged electrothermal arc furnaces. Horizontal retorts are small ceramic cylinders that are mounted horizontally in racks that hold several rows of these retorts in layers. Vertical retorts are large, refractory-lined vessels with external gas combustion chambers. The retorting process is continuous and highly mechanized. The feed consists of a briquetted mixture of the following approximate composition: 60 percent roasted zinc concentrate, 25 percent bituminous coal, 5 percent anthracite fines, 10 percent plastic refractory clay and 1 percent sulfite liquor. The briquets are charged into the upper unheated extension of the retort, known as the charge column, and the residue briquets are continuously discharged at the bottom. Air is introduced at the bottom of the retort at a low rate, and the oxygen is converted to carbon monoxide. The retort is heated by combustion in the firing chamber external to each sidewall. Good heat conduction is essential through both the sidewalls and the briquetted charge.

The gaseous-reaction products formed in the retort, which rise up through the charge column, have the approximate composition of 40 percent zinc vapor, 45 percent carbon monoxide, 8 percent hydrogen, 7 percent nitrogen and some carbon dioxide. These gases exit near the top of the charge column through a zinc vapor condenser. In the condensation process, a back oxidation reaction is responsible for the production of 3 to 5 percent partially oxidized zinc powder. This zinc oxide, known as blue powder, floats on top of the zinc bath and is periodically skimmed off. A scrubber system may be used to scrub out the entrained blue powder from the flue gases and this cleaned gas may be used as supplementary fuel or flared. The zinc thus produced may be further refined. About one-half of the zinc produced in vertical retorts is refined to 99.99 percent purity by means of continuous fractional distillation.

Electrothermic furnaces, such as the one graphically depicted in Figure 34.1, may be used for either zinc or zinc oxide production. Preheated coke and zinc-bearing sinter are continuously fed to the furnace; electricity is introduced through graphite electrodes and coke serves as the principal electrical conductor so the developed electric heat provides the energy required for smelting. Zinc is recovered through condensation by bubbling through a molten zinc bath and zinc oxide may be produced by oxidizing zinc vapors with air. The zinc oxide fume-laden gases are cleaned by cyclones to remove oversized particles and foreign material, then zinc oxide is removed either by bag filtration or high energy wet scrubbing.

34.2 Process Control Operation

Atmospheric emission of pollutants from electrolytic zinc reduction is limited to minor amounts of sulfuric acid mist but disposal of liquid

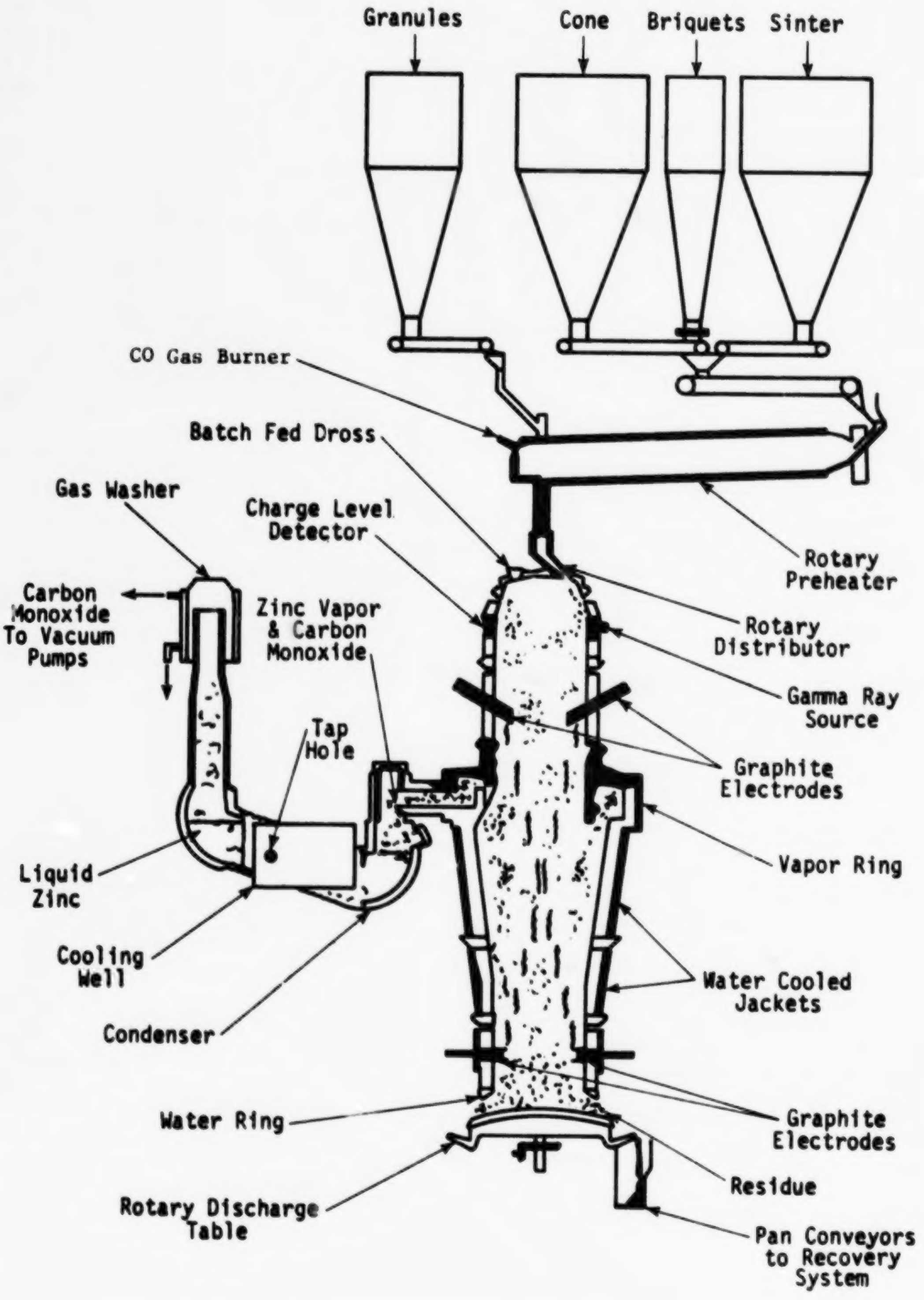
Granules
Cone
Briquets
Sinter
CO Gas Burner
Batch Fed Dross
Gas Washer
Charge Level Detector
Rotary Preheater
Carbon Monoxide To Vacuum Pumps
Zinc Vapor & Carbon Monoxide
Rotary Distributor
Gamma Ray Source
Tap Hole
Graphite Electrodes
Vapor Ring
Liquid Zinc
Cooling Well
Water Cooled Jackets
Condenser
Water Ring
Graphite Electrodes
Residue
Rotary Discharge Table
Pan Conveyors to Recovery System

FIGURE 34.1 ELECTROTHERMIC ZINC METAL FURNACE

wastes can create a significant water pollution problem. Emissions from retort furnaces are of minor significance compared to other operations like concentrate roasting and sintering. Of the total sulfur in the raw concentrate, only 0.2 to 0.3 percent is emitted from retort furnace operations. Particulate emission, which consists primarily of metal and metal oxide fumes, is minor because economics dictate a high-efficiency metal recovery. Because the retort off gases are rich in carbon monoxide, they are used as auxiliary fuel either in the retort furnaces themselves, or in other smelter operations. Retort off gases are commingled with combustion by-products, thus seldom are they directly vented.

The important process variables are the zinc and coke content of the feed, the feed, and air flow rates. Proper air flow rate is important for the production of carbon monoxide, the reducing agent, since too much air might result in nearly complete combustion of coal.

The most important process parameter is temperature. Process temperature is regulated by fuel rate adjustment for conventional retort furnaces and by regulating current flow to the electrodes for electrothermic furnaces. The normal process temperature range is between 1,800 and 2,400°F.

The gases leaving the furnace at essentially atmospheric pressure bubble through the molten condensed zinc. Gas cleaning consists of particulate removal which may be cyclone removal of oversized particles followed by bag filtration after cooling, or high energy wet scrubbing. The cleaned gases, rich in carbon monoxide, are recycled and used as auxiliary fuel.

34.3 Enforcement Procedure

Zinc oxide is a fine, highly-visible white particulate, the major pollutant emitted from the retort furnaces. The retort furnace is an entirely closed system except during charging or when a hole occurs in the wall of the furnace. There are many retort furnaces at a zinc production facility and most of these are older furnaces where leaks can occur if not maintained properly. The enforcement official should ask about the maintenance schedule used on the furnaces and specifically the maintenance schedule for the furnace walls.

The enforcement official should also observe the stack plume. If a white cloud is present, it is an indication that the air pollution control equipment may not be operating satisfactorily. Most plants will have an opacity meter located on the stack to warn of any upsets in the furnace condition. Opacity meter charts (if available) should be reviewed, as well as dust collector maintenance records.

The enforcement official should obtain information from the operator's daily logs on the process operation. The important variables are listed on the Inspector's Work Sheet shown on the next page. There is little telltale evidence that can be collected while standing on the floor of the plant; therefore, the enforcement official should carry out his inspection program at the control booth for the retort furnaces and at a distance from the building so that he can observe the stack plumes for this operation. Observations of the opacity of the stack plumes should be made and if opacity exceeds allowable levels, appropriate action should be taken.

INSPECTORS WORKSHEET

FOR ZINC RETORT FURNACES

Plant Id.____

Date of this Inspection____________ Date of last Inspection____________

Type of Retorts____________________________

No. of Retorts, entire plant____________________

No. of Stacks for Retort furnaces____________________

No. of Retorts out of service this day____________________

Process feed rate, entire retort plant____________________tons/hr

ABATEMENT EQUIPMENT (fill out for each device)

Pressure drop____________________in. H_2O

Spark rate____________________spm

Flow rate____________________scfm

Inlet Temperature____________________°F

Opacity Meter Reading________________%

DIAGRAM OF RETORTS, ABATEMENT EQUIPMENT AND STACKS

GENERAL OBSERVATIONS:

Time In________________ Time Out____________

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PART VI

AIR POLLUTION CONTROL SYSTEMS

PART VI

AIR POLLUTION CONTROL SYSTEMS

Particulates are the principal pollutant from the five metal industries covered in this report. The air pollution control devices which have been used to abate particulate emissions include electrostatic precipitators, fabric filters, wet scrubbers, and cyclones. In the copper, lead, and zinc industries, sulfur dioxide emissions are significant. The most effective method for reducing sulfur dioxide emissions to the atmosphere has been with sulfuric acid plants. However, this particular type of "abatement device" is not part of the scope of work for this particular project and will not be treated in this section. In the aluminum industry, the major air pollutant is fluoride. Two different types of controls have been used to reduce fluoride gases from these operations, low energy wet scrubbers and dry adsorption processes. The low energy wet scrubbers are discussed as part of this section and the dry adsorption process is discussed in Chapter 16. Table VI-1 is a list of the common particulate control devices used by these major metals industries.

There are several factors which affect the selection of the gas cleaning unit for a particular operation. These include the volumetric flow rate, the variability of the gas flow, particulate concentration, allowable pressure drop, product quality requirements, and the required collection efficiency. Particle size gradients in the inlet gas stream are also an important factor in selecting the proper abatement device. Particles larger than about 15 microns are usually removed effectively by inertial separators such as cyclones. For those sources which have particles smaller than 15 microns and with many of them being smaller than one micron (submicron), medium and high energy scrubbers, fabric

Table VI-1. USE OF PARTICULATE COLLECTORS BY INDUSTRY

Industrial classification	Process	EP	MC	FF	WS	Other
Rock products	Cement	0	0	0	+	----
	Phosphate	0	0	0	0	----
	Gypsum	0	0	0	0	----
	Alumina	0	0	0	+	----
	Lime	0	0	+	----	----
	Bauxite	0	0	----	----	----
	Magnesium oxide	+	+	----	----	----
Steel	Blast furnace	0	----	----	0	+
	Open hearth	0	----	----	+	+
	Basic oxygen furnace	0	----	----	0	----
	Electric furnace	+	----	0	0	----
	Sintering	0	0	----	----	----
	Coke ovens	0	----	----	----	+
	Ore roasters	0	0	----	+	----
	Cupola	+	----	+	0	----
	Pyrites roaster	0	0	----	0	----
	Taconite	+	0	----	----	----
	Hot scarfing	0	----	----	+	----
Mining and metallurgical	Zinc roaster	0	0	----	----	----
	Zinc smelter	0	----	----	----	----
	Copper roaster	0	0	----	----	----
	Copper reverb	0	----	----	----	----
	Copper converter	0	----	----	----	----
	Lead furnace	----	----	0	0	----
	Aluminum	0	----	----	0	+
	Elemental phos	0	----	----	----	----
	Ilmenite	0	0	----	----	----
	Titanium dioxide	+	----	0	----	----
	Molybdenum	+	----	----	----	----
	Sulfuric acid	0	----	----	0	0
	Phosphoric acid	----	----	----	0	0
	Nitric acid	----	----	----	0	0
	Ore beneficiation	+	+	+	+	+

Key:

0 = Most common
+ = Not normally used
EP = Electrostatic Precipitator
MC = Mechanical Collector
FF = Fabric Filter
WS = Wet Scrubber

Other = Packed towers
Mist pads
Slag filter
Centrifugal exhausters
Flame incineration
Settling chamber

filters, or electrostatic precipitators will have to be used to clean the gas stream. Figure VI-1 indicates the type of control systems that can be used on various size particles.

Once the technological considerations have been made for selecting control systems, general operating factors play an important role in final selection. For example, the disadvantages of wet scrubbers include the potential water pollution problem, high power costs, and the presence of a visible plume. Fabric filters and electrostatic precipitators capture particles without any physical modification and the collected material can readily be reused in the process. However, fabric filters have a temperature limitation and are sensitive to process conditions. Electrostatic precipitators have few moving parts and low power requirements but are sensitive to variable dust loadings and variable flow rates. Because of the wide variations in process operating conditions, different types of control devices may be found on the same source at different plants.

The following discussion on electrostatic precipitators, fabric filters, wet scrubbers, and cyclones provides some background with respect to the technological considerations applicable to an abatement system. Air pollution control systems for a single source may include different control devices in series and in parallel. Particulates coming from roasters in a lead smelter will often go through cyclones to remove the large particulate matter prior to entering electrostatic precipitators. Non-ferrous sintering machines may have the wind boxes divided into several sections with the primary combustion gases going to one kind of control device, say a sulfuric acid plant, and the secondary combustion zone gases going to a different kind of collector.

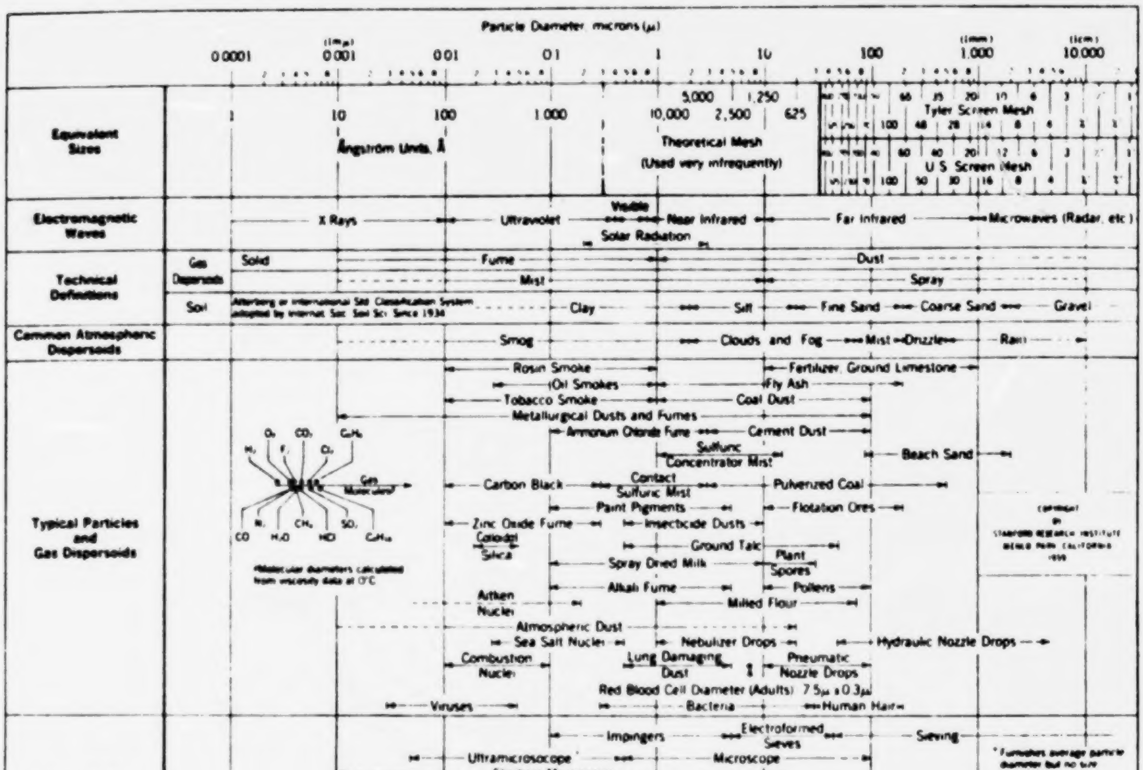


FIGURE VI-1 CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSIONS

There are many existing air pollution control regulations which apply to the maintenance of air pollution control systems. Generally speaking, the laws will require that all air pollution control devices be maintained in good operating condition. Thus, unbalanced fans, excessive spark rates, holes in the ducts and water entrainment are indications that the control system has not been maintained in good operating condition. Observations of concern to an enforcement official when inspecting an air pollution control system are included in the following chapters.

35. ELECTROSTATIC PRECIPITATORS

The theory of the successful operation of the electrostatic precipitator will not be discussed in detail in this chapter, since it has been carefully documented academically. Interest is in the actual field application of the precipitator. Basically, there are two types of precipitators used in these five industries: wire-in-plate and wire-in-cylinder. Because of the nature of the air contaminants, plate-type precipitators are predominantly used to reduce particulate emissions. The wire-in-cylinder type precipitator is best applied to wet gas cleaning, which is uncommon in these industries. Figures 35.1 and 35.2 are diagrams of the wire-in-cylinder and wire-in-plate type precipitators.

There are several parameters which are important in selecting the size of precipitator. These include the volume of gases to be treated, the resistivity of the particulate, particulate size, and dust loading. Of these, resistivity and dust loading are the most important. The resistivity is dependent upon the nature of the pollutant. Most of the pollutants associated with these five industries have resistivity values between 10^7 and 10^9 ohm-cm. Dust loadings may range from several hundreths to 100 gr/scf depending on the manufacturing process.

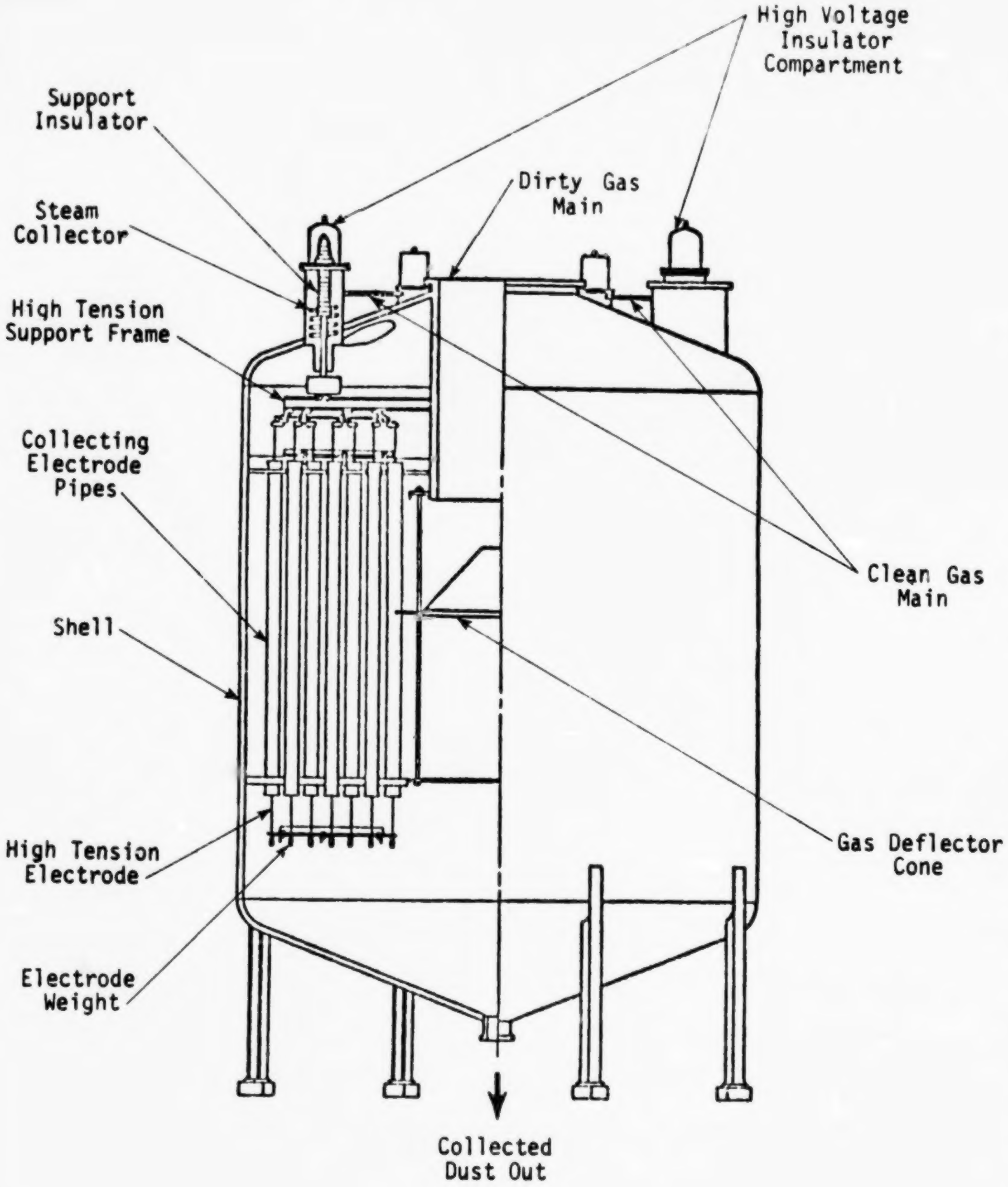

High Voltage Insulator Compartment
Support Insulator
Dirty Gas Main
Steam Collector
High Tension Support Frame
Collecting Electrode Pipes
Clean Gas Main
Shell
High Tension Electrode
Gas Deflector Cone
Electrode Weight
Collected Dust Out

FIGURE 35.1 A SINGLE-STAGE VERTICAL WIRE AND PIPE UNIT

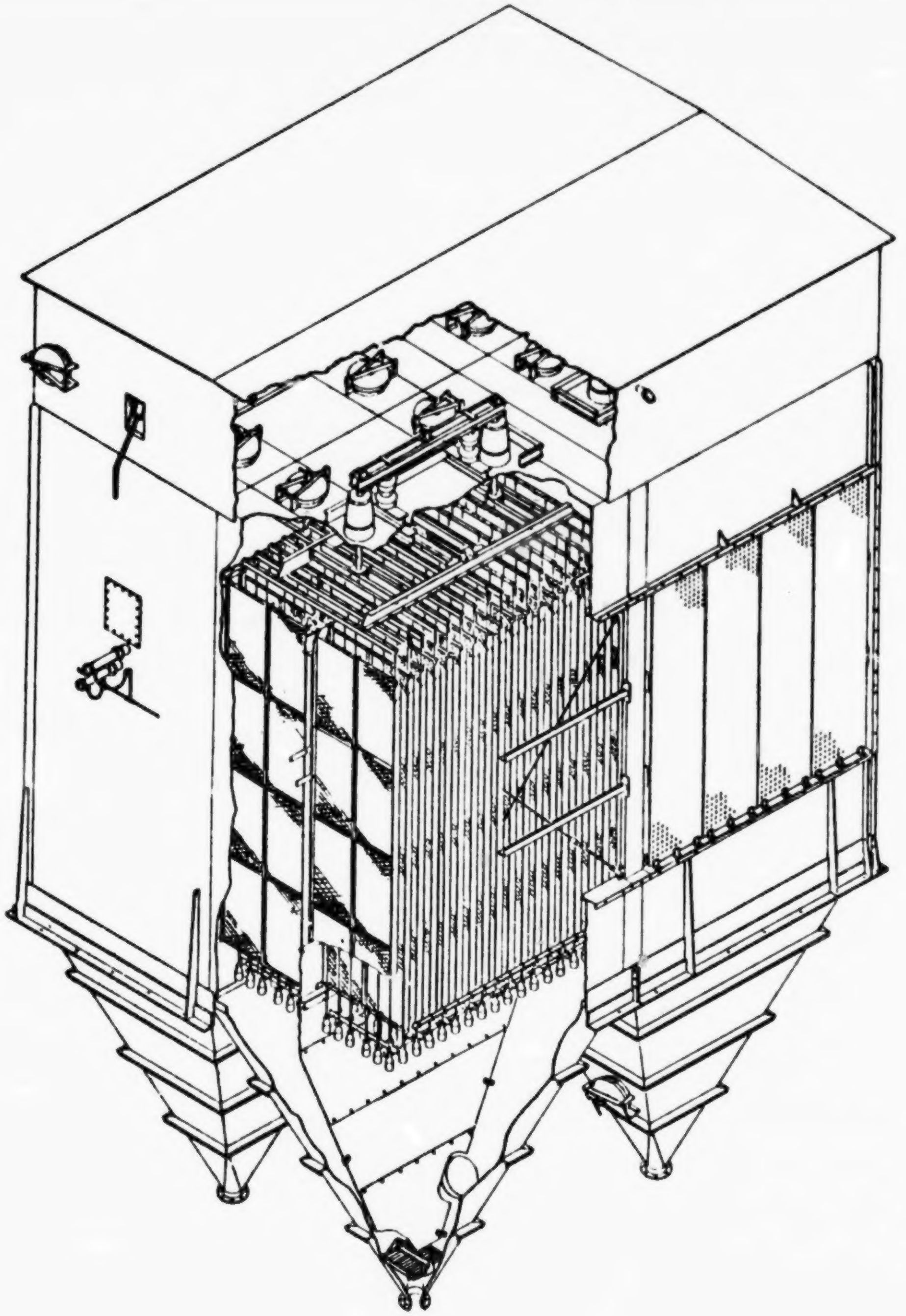


FIGURE 35.2 PARALLEL PLATE PRECIPITATOR

An equation which relates efficiency with gas flow rate and collection area of the precipitator is:

$$E = 1 - e^{-(w A/V)}$$

Where: A = Area of collecting surface

V = Gas flow rate

w = Precipitator rate parameter

E = Efficiency percent

e = Base of natural logarithm

This equation can be used to calculate the collecting surface area required for a specified volume of gases. The critical parameter in that equation is "w", the precipitation rate. The precipitation rate is an indication of the speed at which particles will migrate to the collecting electrode. Precipitation rate varies with respect to each individual application. For smelters, the precipitation rate is 0.35 fps. For open hearth steel making furnaces it is 0.06 fps. For BOF furnaces it ranges between 0.20 and 0.46 with an average of about 0.36 fps. Other precipitator parameters which are important for the effective removal of particulates from a gas stream include spark rate and corona power. Typical spark rates for these heavy metal industries will usually range between 50 and 250 sparks/minute. At no time should a precipitator for these industries be operating with a spark rate in excess of 400 sparks/minute. To a certain degree, spark rate will depend on the physical condition of the precipitator. Corrosion, reduced electrical insulation, and particulate build-up may cause excessive sparking. On the other hand, a low spark rate, on the order of 10 to 20 sparks/minute, would indicate a deficiency in precipitator power, therefore, reduced efficiency.

The electrical energy necessary to charge a particle and bring it in contact with a collecting surface is unique to each specific application. Generally speaking, the corona power will range from 200 to 300 watts per 1,000 cfm of gases treated for these metals industries.

Once the particle has been deposited on the collecting surface, it must be removed. A dust build-up would prevent further ionization and reduce the overall efficiency of the precipitator. Particulate is removed from the plates and the wire by vibrators or rappers. These are mechanical means for removing the dirt from the electrodes. The rappers and vibrators will knock the agglomerated particulates to the bottom of the precipitator where it is collected in hoppers. There is no set rapping rate or average rapping rate that can be associated for each of these large metals industries. Each precipitator will have its own rapping or vibrating sequence.

Another critical operating parameter of a precipitator is the gas flow rate. In most cases, the gas is preconditioned to meet the design specifications of the electrostatic precipitator. Often, the gas comes from a furnace at extremely high temperatures and is cooled by water sprays or dilution air to a temperature of $500^{\circ}F$ on the inlet side of the unit. It is very important that the distribution of the gas through the precipitator be uniform. This is usually accomplished by straightening vanes and distribution vanes. Figure 35.3 illustrates the poor efficiencies associated with the irregular flow velocity. At a flow velocity of 0.5 meters per second (mps) there is an efficiency of 99.4 percent. While in another section of the precipitator, where the flow velocity is 1.5 mps the efficiency is only 91 percent.

Depending on the specific installation, the precipitator may be designed to have several sections or several units. A unit connotes parallel gas flow and a section connotes gas flow in series; therefore, for

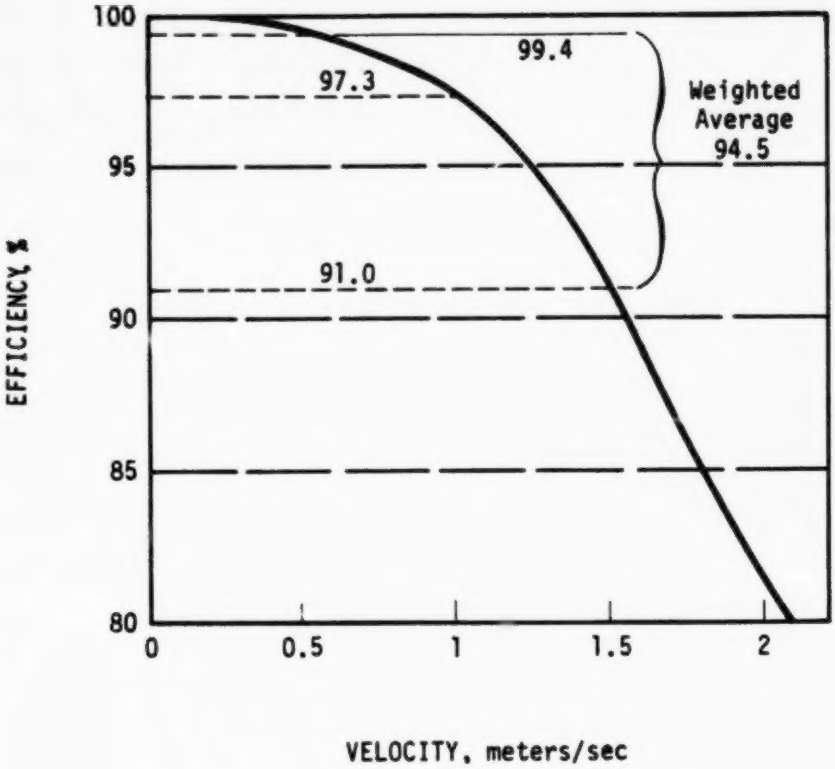


FIGURE 35.3 EFFECT OF NON-UNIFORM VELOCITY ON PRECIPITATOR COLLECTION EFFICIENCY

a precipitator installation which has two units, 50 percent of the gas will be treated by one unit, and 50 percent of the gas will be treated by the other unit. A unit may have several sections and for these heavy metals industries it is common to find up to four sections for each of the precipitators. The principal advantage of sectionalizing is with respect to down-time of the precipitator. For example, if one section of a four sectional precipitator became inoperative, the remaining three could control particulate levels, although not as efficiently.

The type of monitoring instruments that are available for an electrostatic precipitator installation will include meters to measure spark rate, voltage and current. Typical voltages for these industries will be on the order of 20 to 100 kv and the average current is about 1000 ma or 1 amp.

35.1 Precipitator Inspection

Manufacturers of electrostatic precipitators have usually designed precipitators for specific applications. It is unlikely that identical precipitators would be found, even in the same metals application. Such things as corona power, precipitation rate, type of plates, and gas temperatures will vary from furnace to furnace and also from plant to plant. It is the intent of this sub-section of this chapter to identify those general operating characteristics and inspection points which can be observed when a precipitator is in operation. Observation of marked increase in plume opacity is one indication that the precipitator may not be operating properly.

Causes for precipitator malfunction include: electrical, gas flow, and physical. Most electrostatic precipitator service men have indicated that it is the electrical system of the precipitator which is most often the cause of malfunction. If there is any doubt as to the operability of the precipitator the electrical meters should be checked first. Older precipitators will have problems with the rapping or vibrating scheme and the physical abrasion caused by the pollutants. If the precipitator monitoring instruments, spark rate meter, primary voltage meter and primary ammeter indicate that the precipitator is operating normally, yet visual observations indicate poor precipitator efficiency, then it is imperative that the enforcement official obtain the design specifications from the plant operator.

The following step-wise procedure should be used to determine the effective operability of a precipitator. Many items on this check list came from "The Manual of Electrostatic Precipitator Technology."

1. Observe the electrical monitoring instruments for the precipitator. If the spark rate is less than 400 sparks/minute this is considered normal operation; however, a spark rate in excess of 400 sparks/minute is an indication that the precipitator section has shorted out. Record the primary voltage and primary amperage to each of the sections, if a precipitator has four sections, this inspection procedure must be carried out on each individual section. A marked voltage drop in one section of a precipitator is an indication of a dead section and the unit is not operating correctly.

2. Record the gas inlet temperature and gas flow rate. The gas temperature should be between 250 and 500°F. If the temperature is less than 250°F, it is likely that condensation will form in the precipitator, causing malfunction. Temperatures in excess of 500°F cause the plates and wires to warp within the precipitator. Observe the ducts entering the precipitator for corrosion. Corrosion at the exterior ducts is an indication of corrosion on the interior of the precipitator.

3. Open the hatch on several of the precipitator sections. Observe dust deposits on collecting plates, and wires before cleaning. A 1/4-inch deposit is normal, but if the metal plates are clean there is a possibility that a section is shorting out. If more than 1/4-inch of dust is on the plates the rappers and vibrators are not working properly. Observe the amount of corrosion adjacent to the door. Leakage to the interior of the precipitator through the doors could cause non-uniform gas flow and reduce efficiency. Check plate alignments for equal spacing between plates, also check for broken wires at the top of the precipitator.

4. Open the hopper access door for this inspection. Check for leakage into the precipitator around the door and for dust build-up in upper corners of hoppers. Check the high tension weights, if one has dropped more than 3 inches, it is an indication that the wire has broken. Check the hopper bottom for broken precipitator parts, like wires, insulators and plates.

5. Check the electrical distribution center by examining the high tension lines, insulators, bushing, terminals, and arrestors for broken parts. Some minor sparking should be noted in this area.

6. Listen to the rapper or vibrating mechanism which cleans the dust from the plates and wires. A uniform, rhythmic tapping, of metal to metal, should be noted. Any irregular sounds are an indication that the rapper mechanism is not operating correctly.

7. If necessary, make the calculations, which relate efficiency collection area, gas flow rate and precipitator rate. Compare the calculated results to design specifications and ask whether any alterations have been made to the process which might affect precipitator performance.

8. Ask about the routine maintenance schedule for the precipitators, and to see logsheets for any repairs.

36. FABRIC FILTERS

Fabric filter collectors are commonly referred to as baghouses and are perhaps the oldest and most reliable methods of removing dry particulate matter from an air stream. Baghouses have traditionally been designed with a collection efficiency in excess of 99 percent. As mentioned in the previous chapters, these five metals industries are commonly associated with fine particulates (minus 10 microns in diameter). Fabric filters are effective in collecting particulates as small as 0.1 micron and some investigators have measured and collected particulates smaller than 0.01 micron in size. The size of these systems range from one or two bags to as many as many several thousand bags for one system. Figure 36.1 is an illustration of a typical baghouse.

The operating principle of a baghouse is simple, the filter itself acts as a collection medium. When air is passed through the fabric, particles come in direct contact with the fabric and are caught. The air stream or gas is not affected by the fabric filter and passes without interruption to the outlet side of the unit. There are several factors which are special to the design of a fabric filter system. Different fabrics will have different permeabilities. Permeability is associated with the ease at which a gas passes through a fabric. The American Society for Testing and Materials (ASTM) has developed a standard procedure for measuring permeability through new cloth; by keeping the pressure differential to 0.5 in. wg, the flow rate is recorded that passes through a square foot of cloth. Table 36.1 indicates the fabric filter characteristics including air permeability for selected fibers.

The pressure drop commonly found in baghouses in these metals application ranges from 2 to 8 in. of water during normal operation. Average

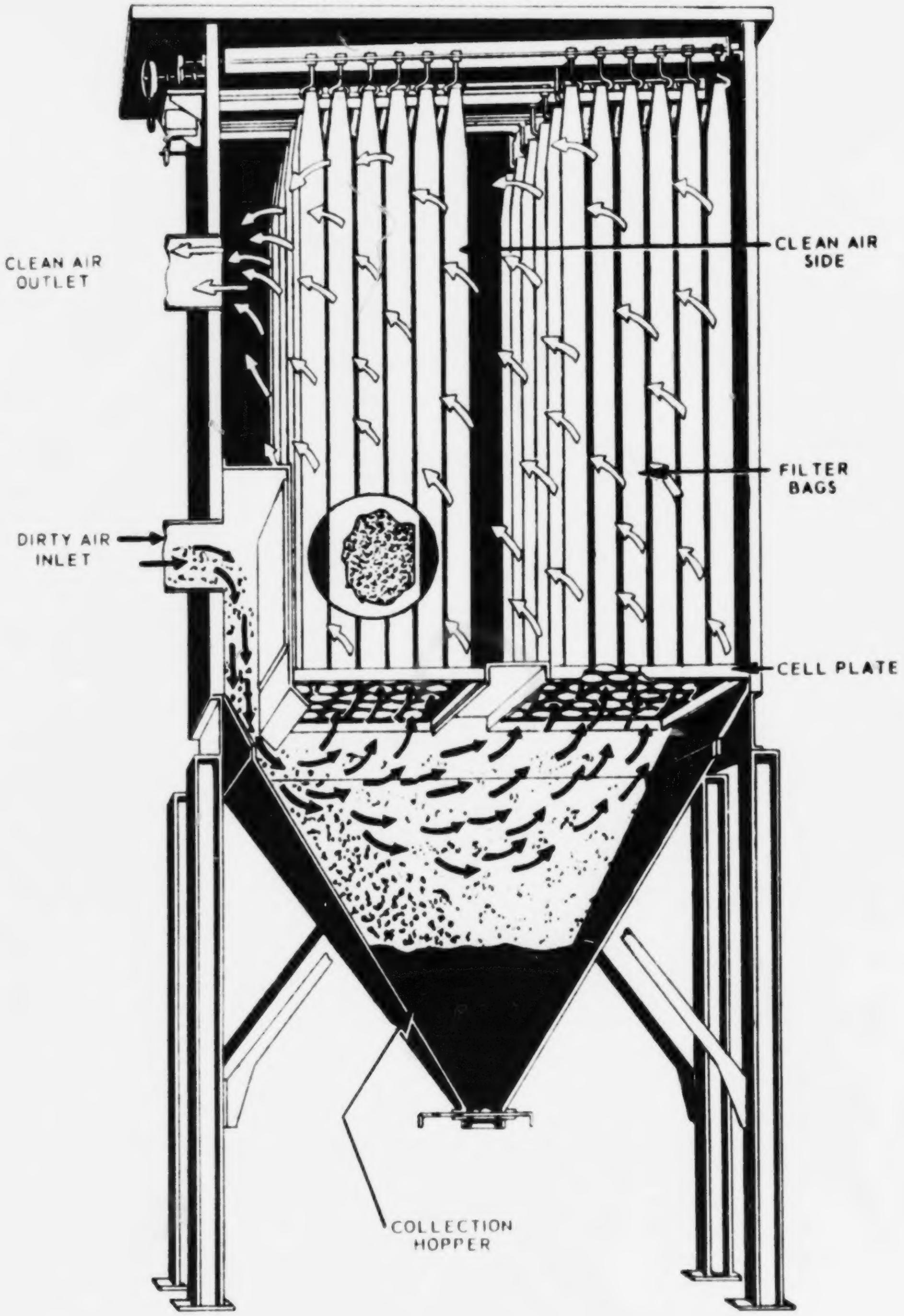

CLEAN AIR OUTLET
CLEAN AIR SIDE
FILTER BAGS
DIRTY AIR INLET
CELL PLATE
COLLECTION HOPPER

FIGURE 36.1 TYPICAL SIMPLE FABRIC FILTER BAGHOUSE DESIGN

Table 36.1 FILTER FABRIC CHARACTERISTICS

Fiber	Operating exposure (°F)		Supports combustion	Air permeability (cfm/ft^2)(1)	Composition	Resistance (2)				
	Long	Short				Abrasion	Mineral acids	Organic acids	Alkali	Cost rank(3)
Cotton------	180	225	yes	10-20	Cellulose	G	P	G	G	1
Wool--------	200	250	no	20-60	Protein	G	F	F	P	7
Nylon(4)-------	200	250	yes	15-30	Polyamide	E	P	F	G	2
Orlon(4)-------	240	275	yes	20-45	Polyacrylonitrile	G	G	G	F	3
Dacron(4)------	275	325	yes	10-60	Polyester	E	G	G	G	4
Polypropylene	200	250	yes	7-30	Olefin	E	E	E	E	6
Nomex(4)-------	425	500	no	25-54	Polyamide	E	F	E	G	8
Fiberglass--	550	600	yes	10-70	Glass	P-F	E	E	F	5
Teflon(4)------	450	500	no	15-65	Polyfluoroethylene	F	E	E	E	9

(1) cfm/ft^2 at 0.5 in. wg.

(2) P = Poor, F = Fair, G = Good, E = Excellent.

(3) Cost rank, 1 = lowest cost, 9 = highest cost.

(4) Dupont registered trademark.

flows are between 1.5 and 3.0 cfm/ft^2 of cloth. This is known as the air-to-cloth-ratio. Baghouses traditionally found in these five metals industries have a maximum filtering ratio, air-to-cloth-ratio, which ranges between 2.0 and 3.5. However, when the bags are cleaned with a reverse air jet stream, the air-to-cloth-ratio increases to about 9 cfm/ft^2.

Moisture and gas temperature are the most critical operating variables for baghouse installation. It is desirable to keep the temperature of the gas 50 to 75^{o}F above the dew point to prevent condensation within the unit. Moisture would cause mud cakes to form on the bags and cause high resistance and ultimate rupture. Because of the physical and thermal characteristics of each of these fibers, the bags will fail at elevated temperatures. The long and short term operating exposure of selected fibers is also shown in Table 36.1. Dacron® is the most popular bag used in these metals industries. Its normal operating temperature is about 270^{o}F. Gases coming from melting and smelting operations from these industries at high temperatures must be cooled before entering the baghouses. Heat exchangers and water spray systems are used to cool the gases. Each of these gas cooling systems must be well designed to prevent moisture and excess temperature in the baghouses.

There are three types of baghouse designs commonly used today: open pressure, closed pressure, and closed suction. Open-pressure baghouses do not have a stack, instead the gases are exhausted through the walls or sides of the baghouse installation. Closed-pressure baghouses are constructed with the fan supplying a positive pressure and the dirty gas to the unit. Because the fan is on the inlet side, it is subjected to the abrasion and wear caused by the air pollutants. In a closed-suction baghouse, the fan is located on the outlet side of the unit, thus the gases at the fan are cleaned and free of abrasive pollutants. One of the problems encountered with a closed-suction baghouse is the tight seal required for the entire installation. Air leaks around access doors, vibrators, and walls may reduce the efficiency of the unit or cause condensation at "cold spots".

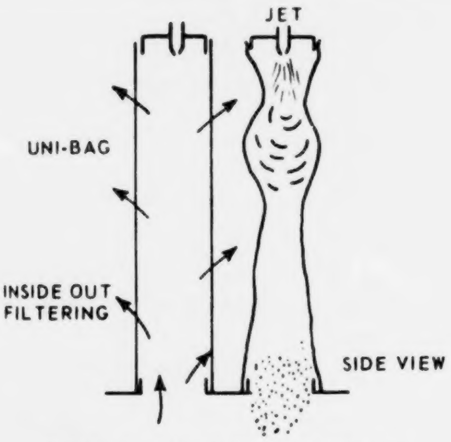
There are several types of manual shaking systems used to clean the bags once they become dirty. The cleaning cycle is based on pressure drop across the bag or a timed cycle. Figure 36.2 illustrates some of the schemes used to remove dust from the fabrics. Each cleaning scheme has its advantages for a specifically designed baghouse. Often baghouses are sectionalized, that is, having several compartments so that one compartment may be cleaned while the others continue to operate. For those baghouses which clean on a pressure drop response, the clean cycle may begin when the pressure drop across the compartment reaches 3 and 4 in. wg. On the other hand, time cycles vary widely, from once a minute to once a day.

Bag life for these metallurgical industries ranges between 18 months and 2 years. There are few operational adjustments which can be made to a baghouse once it has been installed and most likely, the only monitoring instrument for baghouses will be a manometer measuring pressure drop across the entire system. Bags are changed on a regular schedule, also when they rupture.

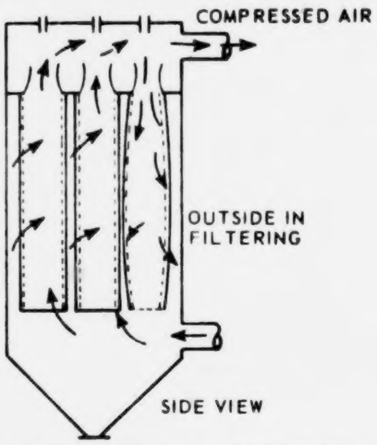
36.1 Enforcement Procedure

The following step-wise procedures should be used to assess the operability of a baghouse abatement installation:

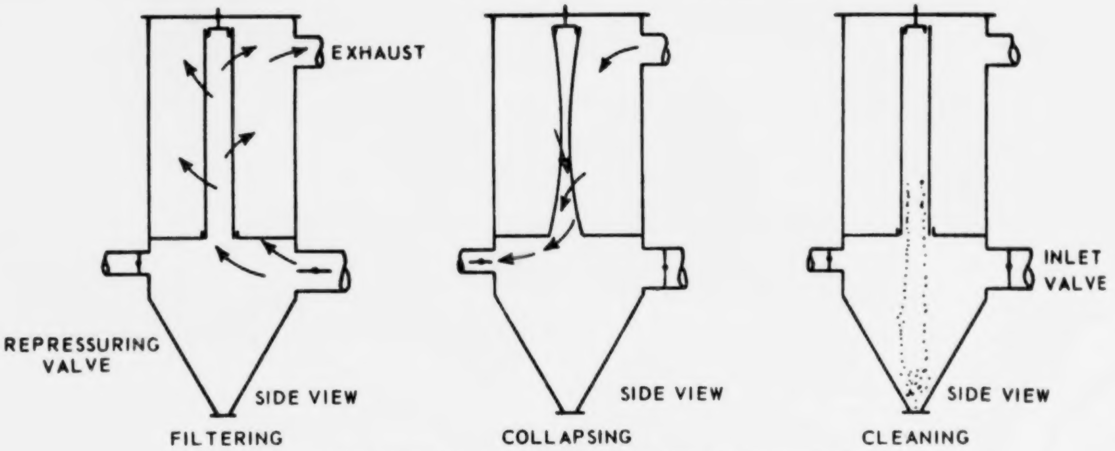
1. Prior to, or upon entry to the plant, obtain design specifications of the baghouse installation. Ask what type of bags are being used and


JET
UNI-BAG
INSIDE OUT FILTERING
SIDE VIEW

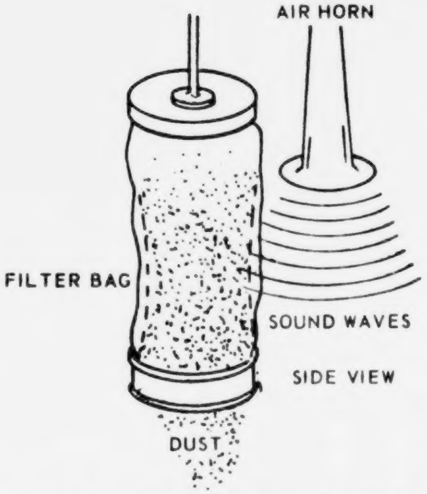
Bubble cleaning of dust collector bags.


COMPRESSED AIR
OUTSIDE IN FILTERING
SIDE VIEW

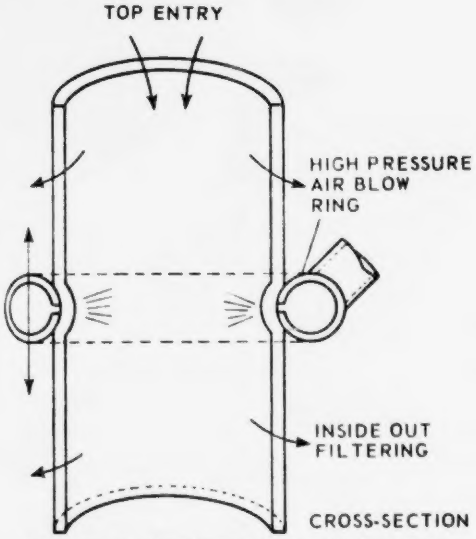
Jet pulse dust collector bag cleaning.


EXHAUST
REPRESSURING VALVE
SIDE VIEW
FILTERING
SIDE VIEW
COLLAPSING
INLET VALVE
SIDE VIEW
CLEANING

Reverse air flexing to clean dust collector bags by repressuring.


AIR HORN
FILTER BAG
SOUND WAVES
SIDE VIEW
DUST

Sonic cleaning of dust collector bags.


TOP ENTRY
HIGH PRESSURE AIR BLOW RING
INSIDE OUT FILTERING
CROSS-SECTION

Reverse jet cleaning of dust collector bags.

FIGURE 36.2 BAGHOUSE CONFIGURATIONS

ask for historical records which would indicate fan size, inlet temperature through the baghouse and pressure drop across the unit. Determine the number bags and collection area of this installation and compare this data to the data in Table 36.1.

2. Observe the cleaning cycle for this particular installation. Determine whether a pressure or time cleaning cycle is used to remove the dirt from the fabric. For a pressure control system, check the controls and their operability to insure that when the pressure drop is reached, cleaning is initiated. For time-cycle cleaning schemes, observe the rhythm for a given period to assure its operability.

3. Check for air leakage into the ducts, fans, access door, baghouse structure, and hopper. For closed-suction baghouses, check the seals on doors, hatches, and hoppers for a tight seal.

4. Observe the unit for an entire cleaning cycle. If the light or dark plume is noted emanating from the stack, it is likely that a rupture or bag failure has occurred but has not been replaced.

5. Measure the wet bulb and dry bulb temperature of the inlet gas stream. Use the section in Part VIII of this manual to determine the dew point of the inlet stream. The dew point should be at least $50^{\circ}F$ above the inlet temperature to prevent moisture build-up on the bags.

6. Observe the manometer or pressure drop across the baghouse sections. After cleaning, the pressure drop across the fabric should be less than when dirty.

7. Observe during the hopper clean out operation.

37. WET SCRUBBERS

There are many types of scrubbers in use in these five metals industries today. The types vary from the most simple design of a water spray in stack to high energy venturi scrubbers. Each manufacturer has his own design on the method for impacting particulate matter in a liquid film. Basically, there are low, medium and high-energy scrubber systems. The energy requirement refers to the amount of power needed to obtain selected pressure drops across the scrubbing system. Low energy scrubbers typically have a pressure drop of up to 12 in. wg pressure. High energy venturi scrubbers can go up to 100 in. wg pressure. For these five metals industries, we are primarily interested in the high-energy capacity scrubber systems. This is mainly due to the nature of the pollutants from these industries. As we have seen in previous chapters, the particle diameter of much of the metal fume is less than one micron. This requires the use of high energy venturi scrubbers on most of these industrial applications. Neither cyclones nor settling chambers have been effective in removing the submicron particle inherent in these metals applications.

The collection principle of wet scrubbing systems is accomplished by impaction of dust with liquid droplets. The particles come in contact, enlarge in size and finally settle out. Once the particle is trapped, it is then washed away. There are no universally accepted equations which relate scrubbing parameters with collection efficiency. Much of the existing scrubber technology has been defined and presented in the reference entitled, "Scrubber Handbook." Basically, the collection efficiency of a scrubber system will depend on the size of the particle. Of particular importance is the particle size and inlet dust loading. Figure 37.1 shows a relationship between pressure drop and outlet grain loading.

Several investigators have tried to relate input power to efficiency. Power refers to the amount of energy necessary to overcome the resistance

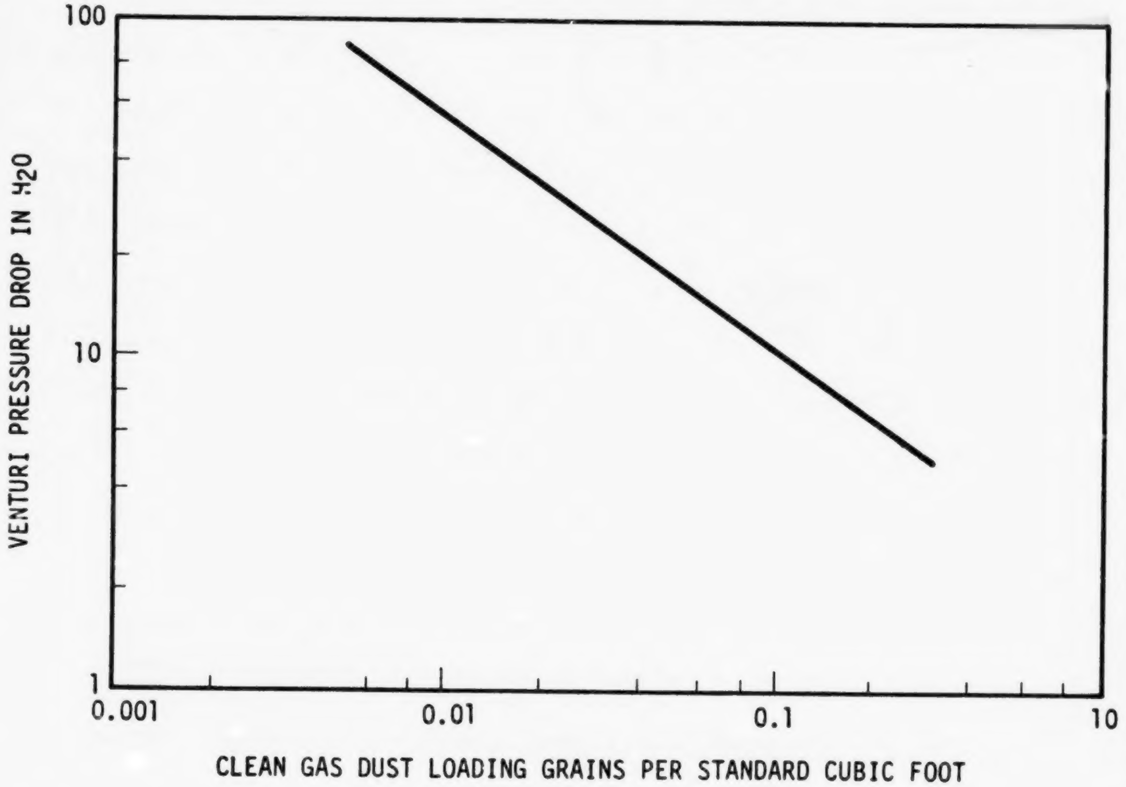


FIGURE 37.1 CALIBRATION CURVE FOR A BLAST FURNACE VENTURI SCRUBBER

caused by a scrubbing system, such as a contracting throat or high pressure sprays. Figures 37.2 and 37.3 show this relationship of contacting horsepower and efficiency for selected metallurgical operations. These curves were developed for specific industrial applications. Generally speaking, it will require about 7 hp/1000 cf of exhaust gases to obtain an efficiency of above 99 percent for the particle diameter typically found in these industries. These relationships were developed for high energy venturi scrubbing systems. Less efficient systems like the impingement plate scrubber does not have the high collection efficiency commonly associated with venturi units; however, a lower efficiency would not require as much contacting horsepower. It is because of the similarity of the metal fume generated in each of these metals industries that these curves supply "ball-park" figures for power requirements for scrubbing systems. As mentioned in the previous chapters, these fumes are fine and many are submicron in size. The pressure drop, which corresponds to the contacting power, will represent the most important scrubber operating variable used to assess the collection efficiency of a unit.

Another fundamental operating parameter of wet scrubber systems is the liquid flow rate in the unit. This parameter is usually expressed in terms of gallons of water per 1000 cf of gas processed. For the high energy venturi systems on these particular applications the flow rate requirement varies between 3 and 10 gal/1000 cf of gas processed. For plate or impingement type scrubbers (low energy units) the flow rate is something less; on the order of 1 to 2 gal/1000 cf of exhaust gases processed. Under normal operation, high energy venturi units have been shown to reduce particulate levels to an exit loading of less than 0.01 gr/scf. Typical throat velocities for venturi units are on the order of 200

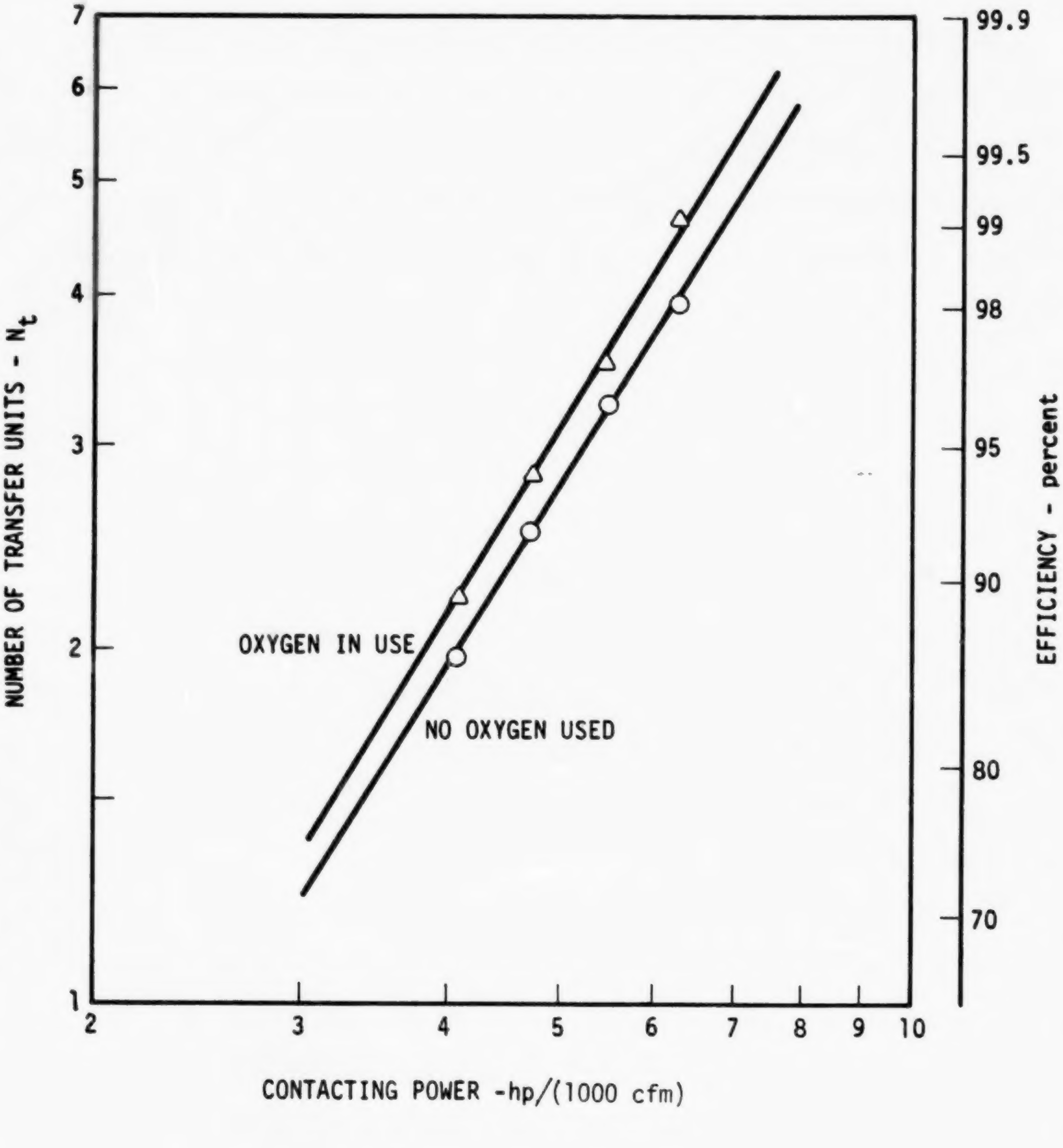


FIGURE 37.2 PERFORMANCE OF A VENTURI SCRUBBER ON AN OPEN HEARTH FURNACE FUME

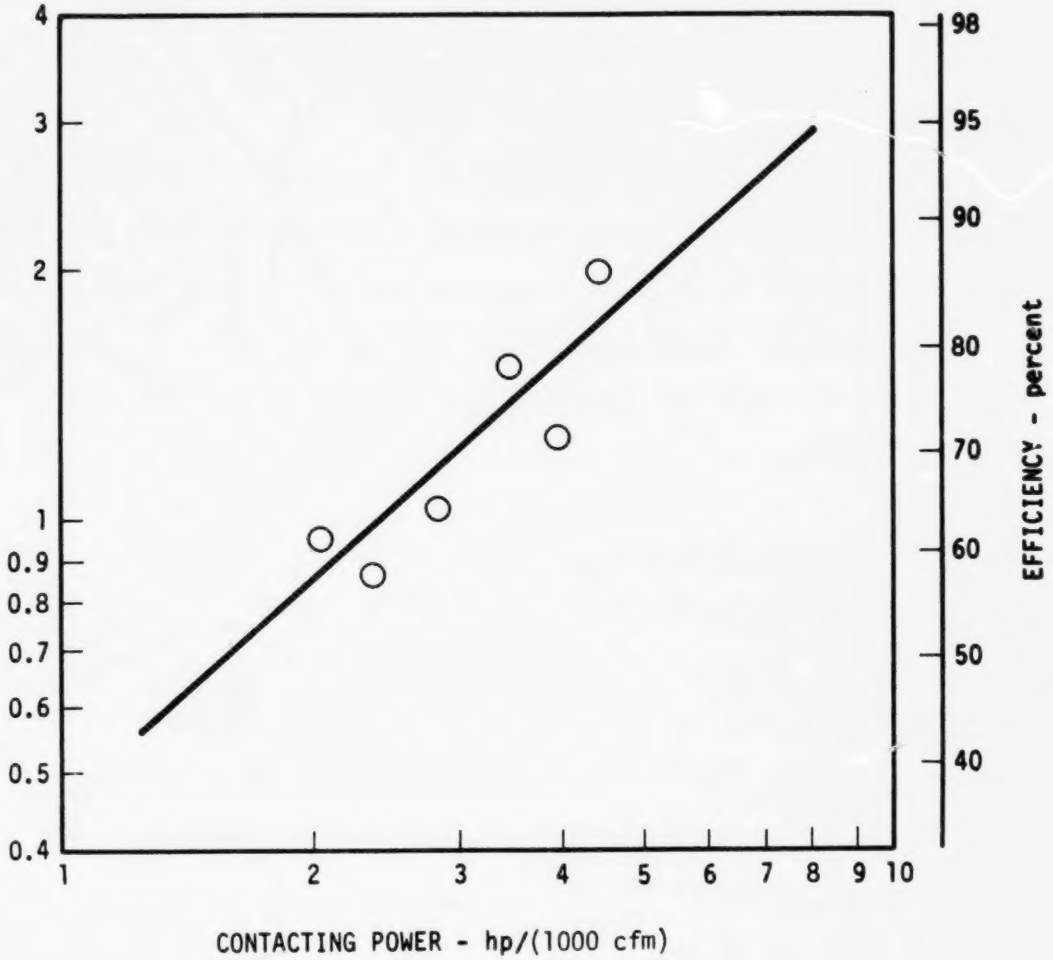


FIGURE 37.3 PERFORMANCE OF A VENTURI SCRUBBER ON A METALLURGICAL FUME

to 600 ft/sec. Packed bed or impingement type scrubbers typically have pressure drops less than 5 in. wg pressure. Figures 37.4 and 37.5 are illustrations of a venturi scrubber and a wet impingement scrubber.

The principal disadvantage of using a venturi unit in lieu of an electrostatic precipitator, fabric filter, or other collection devices is its high annual operating cost. Once installed, the cost of water is much cheaper than that for electrical energy for precipitators, and, in many cases, much cheaper than replacement of bags for the fabric filter systems. The immense horsepower requirements soon offset these savings. Venturi systems in these metals industries typically operate about 60 to 80 in. wg pressure. These systems have a collection efficiency in excess of 99 percent. Packed bed and plate type scrubber systems have an efficiency of between 80 and 90 percent.

37.1 Medium Energy Scrubbers

Medium energy scrubbers refer to those control devices which operate with a pressure drop of up to 14 in. H_2O. Compared to the other types of control systems, these scrubbers usually require a minimum of space. Typical efficiencies for these units will be on the order of up to 90 percent for large dust. Their major application in these metals industries is in the material handling segment of production. These type units are found on transfer points from conveyor systems, and at the end of crushing, screening and grinding operations. In the aluminum industry, low energy scrubbers (up to 8 in. H_2O wg) are the primary air pollution control systems. Hydrogen fluoride gas, which emanates from anode curing ovens, prebake pot and Soderberg pot operations, is very soluble in water and can be effectively controlled by passing it through these scrubber systems. Figures 37.6 and 37.7 are illustrations of a flooded-bed

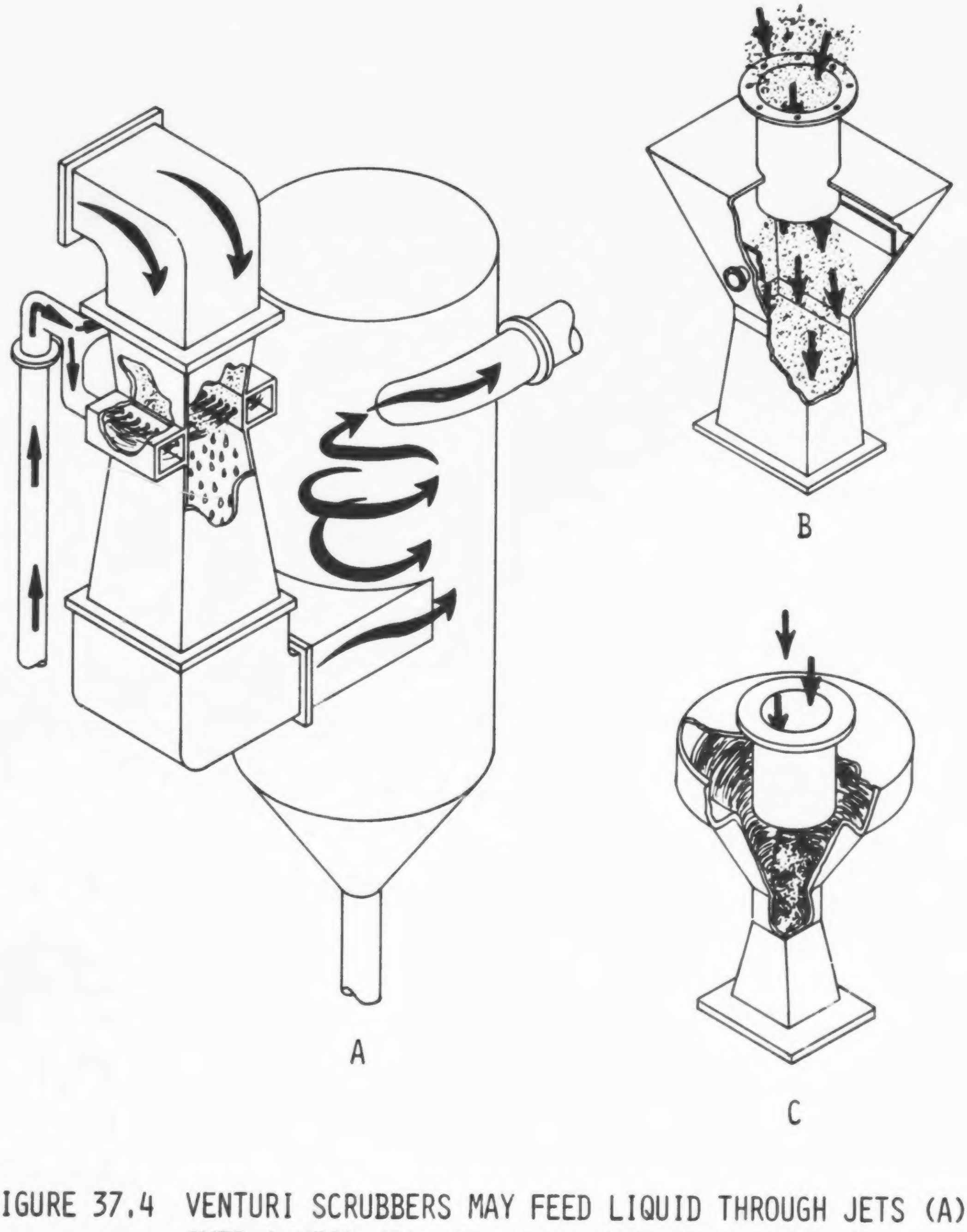
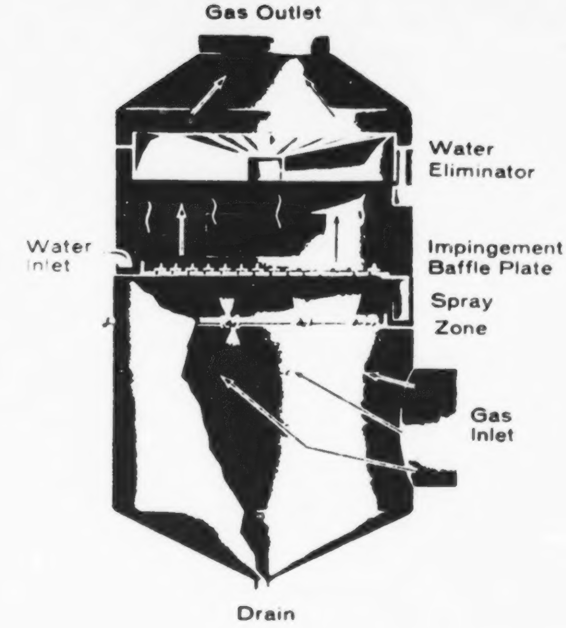


FIGURE 37.4 VENTURI SCRUBBERS MAY FEED LIQUID THROUGH JETS (A), OVER A WEIR (B), OR SWIRL THEM ON A SHELF (C)


Gas Outlet
Water Eliminator
Water Inlet
Impingement Baffle Plate
Spray Zone
Gas Inlet
Drain

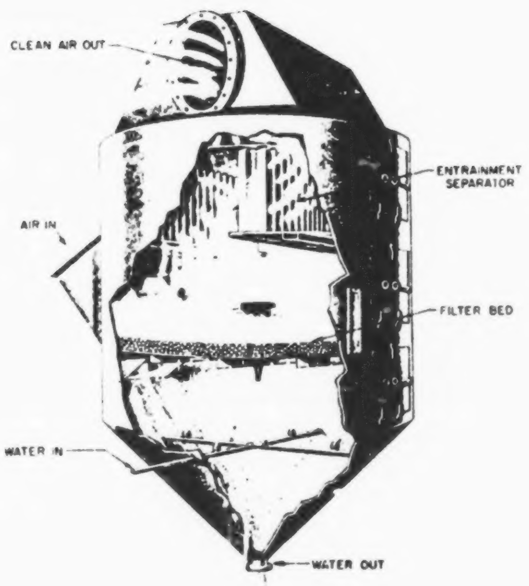

CLEAN AIR OUT
ENTRAINMENT SEPARATOR
AIR IN
FILTER BED
WATER IN
WATER OUT

FIGURE 37.5 WET IMPINGEMENT COLLECTORS

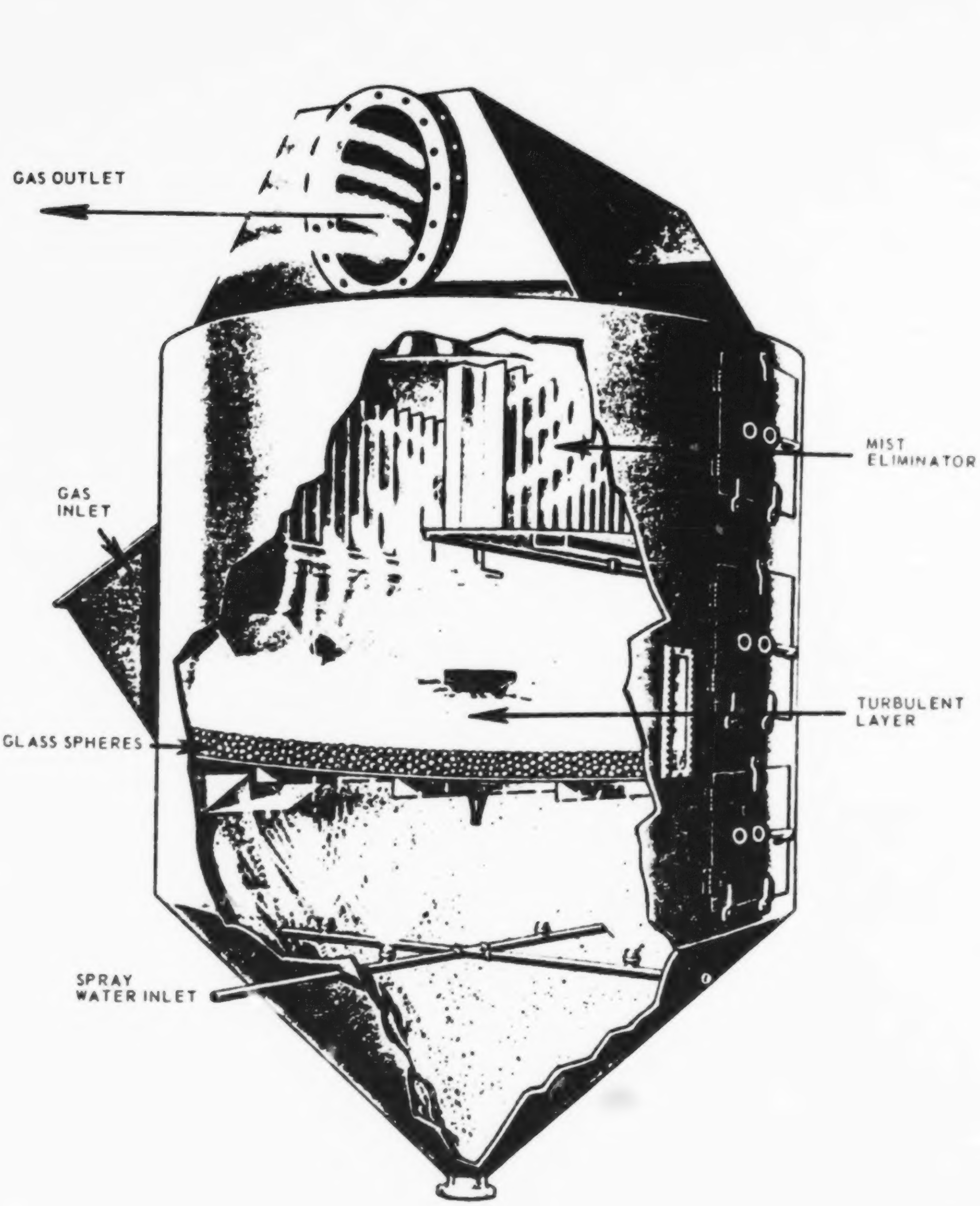

GAS OUTLET
MIST ELIMINATOR
GAS INLET
TURBULENT LAYER
GLASS SPHERES
SPRAY WATER INLET

FIGURE 37.6 FLOODED BED SCRUBBER

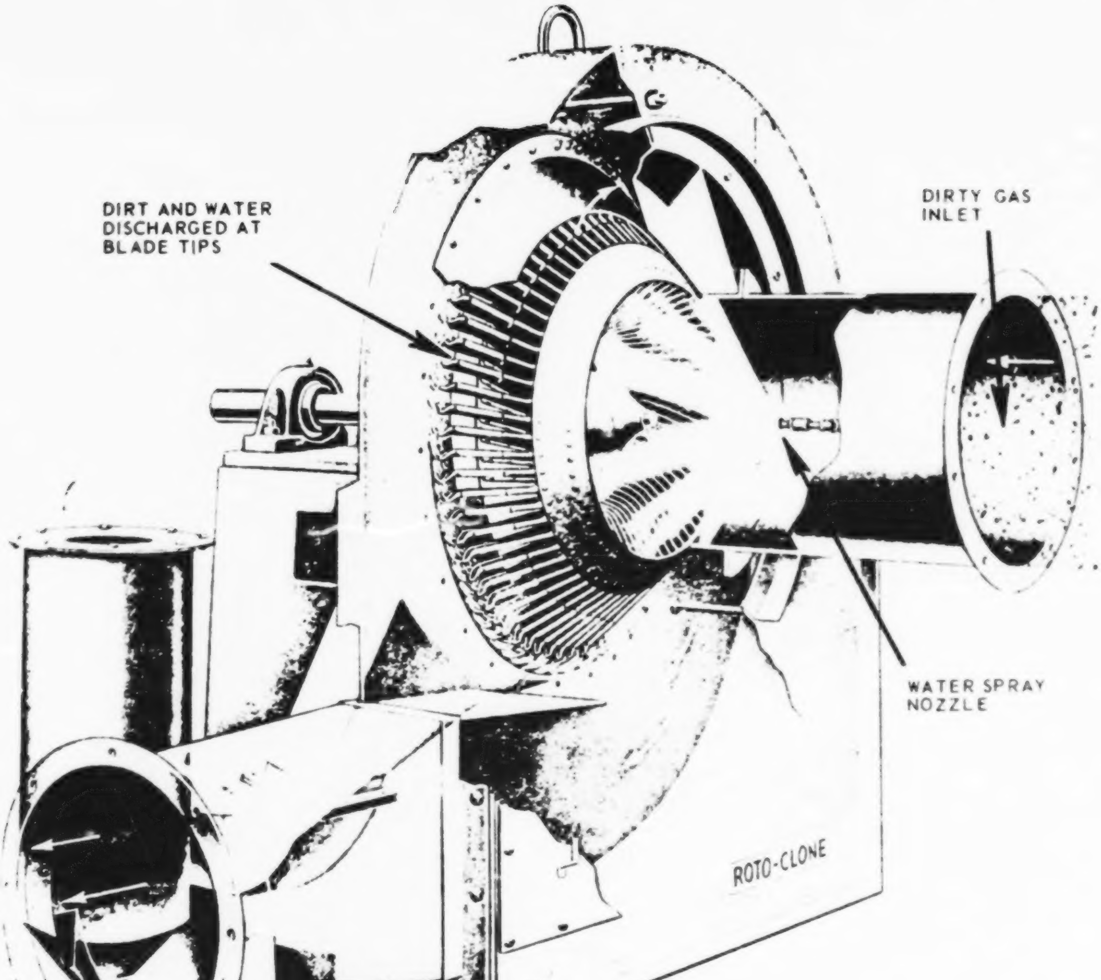

DIRT AND WATER
DISCHARGED AT
BLADE TIPS
DIRTY GAS
INLET
WATER SPRAY
NOZZLE
ROTO-CLONE
CLEAN GAS
OUTLET
WATER AND
SLUDGE OUTLET

FIGURE 37.7 CENTRIFUGAL FAN SCRUBBER

scrubber and a centrifugal fan wet scrubber. Flooded-bed scrubbers similar to Figure 37.6 are the ones that are used to remove hydrogen fluoride gas. The centrifugal wet scrubber is the type of system that would be used on many material handling sources. Figure 37.8 will provide some idea of the fan horsepower required for various sized installations.

37.2 Enforcement Procedure

In this subsection it is impractical to discuss typical operating parameters for each industrial application because of the numerous scrubber designs. Certain things are similar for scrubbers applied to these industries. One of the easiest parameters used in assessing the performance of a scrubber is the contacting horsepower and corresponding flow rate. The horsepower rating is available on nearly every motor in the form of a name plate on the frame of the motor housing. Flow rate can be measured or obtained from fan curve data. A scrubber installation will contain a manometer which would indicate the pressure drop across the scrubber. Amperage of the fan, line voltage and water flow rate in the system are necessary parameters in assessing the operability of the scrubbing system.

The following step-wise procedure will assist the enforcement official in determining whether or not a scrubbing system is working effectively:

1. Obtain the horsepower rating of the motor or motors involved in moving the gas stream through the scrubbing system. Determine the fan capacity for each of the fans in the system, in terms of scfm. Compare this power/flow rate ratio to the above mentioned figures for these type industries. Ascertain that this unit has been properly sized for this particular installation.

2. Inspect the fan for vibration. Excessive vibration may cause the fan, ducts, and scrubber components to rupture.

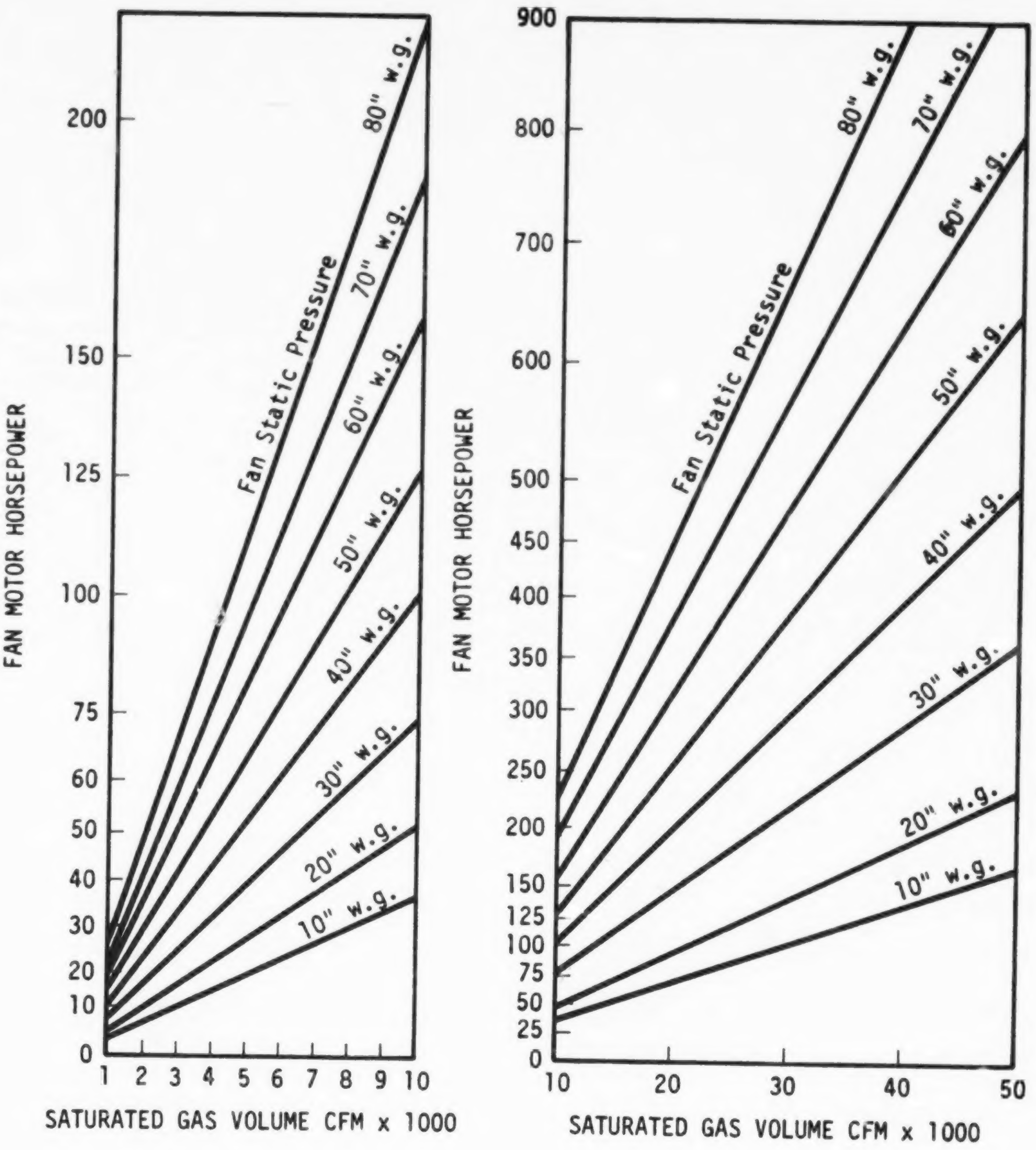


FIGURE 37.8 FAN HORSEPOWER REQUIREMENTS FOR VARIOUS SIZE SCRUBBERS

3. Check for the distribution of water at the throat or in the packed bed system. Some venturi systems will have gauges which indicate the pressure supply to each nozzle or each section of a particular throat. Observe and insure that these pressures are nearly the same for each section or each nozzle. A deficient pressure indication for a nozzle or section would indicate that the proper amount of water is not being supplied for the ensuing air stream, thus reducing the overall efficiency of the collection system.

4. Record the temperature of the inlet gas stream to the scrubber. Temperatures to the scrubber will be on the order of 250 to 500°F. If the inlet temperature is less than 250°F, it is likely that condensation will form in the ducts, causing plugging.

5. Inspect the interior of the scrubber for scaling and particulate build-up. For venturi systems, inspect the interior of the throat carefully for caking and other particulate build-up. Any caking that causes an uneven distribution of the gas stream across the throat would reduce the overall collection efficiency of the scrubber. Inspect the mist eliminator for mud build-up.

6. Observe the water effluent from the scrubber system. A mud slurry should be noted. Compare the water flow rate for this scrubber installation with the values mentioned above.

7. Obtain the pressure drop across the entire scrubbing system. Compare this pressure drop to those values cited for typical installations. If possible, obtain design specifications for the scrubber installations and compare the operating parameters, flow rate, horsepower, pressure drop and water flow rate, to the design specification.

38. CYCLONES

Cyclones are the least efficient air pollution collection device that has been used in these metallurgical industries. Cyclones work on a principle of centrifugal force and gravitational settling to remove large particulate matter from gas streams. Cyclones work well in removing particulates greater than 10 microns in diameter. With that size particle, cyclones and multicyclones have shown an excess of 80 percent removal efficiency.

Figure 38.1 illustrates the conventional reverse-flow cyclone. The inlet gas stream is tangentially applied to the cyclone. The exhaust gas is removed through the center of the unit. The centrifugal action in the cyclone causes large particles to settle to the base of the cyclone where they are removed periodically. Figure 38.2 indicates the kind of efficiency that can be found in various mechanical collectors which may have a load of 4.6 gr/cf.

Cyclones are still used in modern air pollution abatement systems. Generally they serve as a preliminary knock-out chamber to remove the very large particles from many of these metallurgical operations. Precipitators may encounter operational problems if varying loads of fine and large dusts are cleaned in these systems. In these systems, cyclones may be only 50 percent effective, yet remove virtually all of the large particles. The particle size range for these metals operations is normally considered to be fine particulate. This would include particles down to 0.1 microns. As can be seen from Figure 38.2, cyclones have little effect on particles in this size range.

38.1 Cyclone Inspection

The successful operation of a cyclone depends on its physical condition. Power requirements, pressure drop, temperature, and moisture have

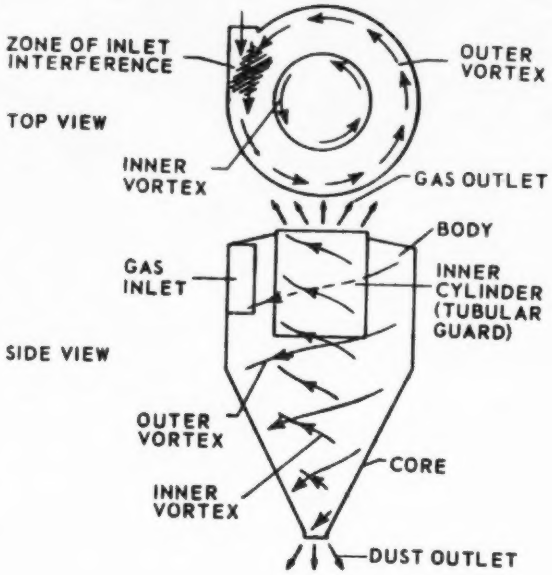

ZONE OF INLET INTERFERENCE
OUTER VORTEX
TOP VIEW
INNER VORTEX
GAS OUTLET
BODY
GAS INLET
INNER CYLINDER (TUBULAR GUARD)
SIDE VIEW
OUTER VORTEX
CORE
INNER VORTEX
DUST OUTLET

FIGURE 38.1 CONVENTIONAL REVERSE-FLOW CYCLONE

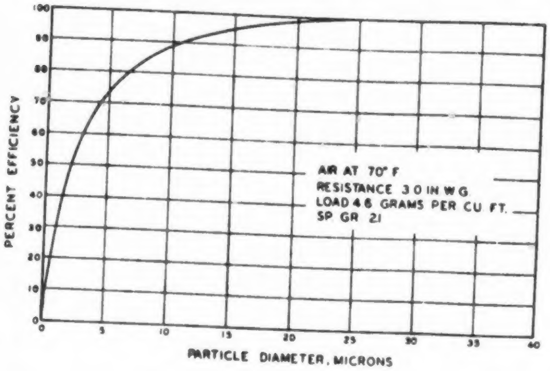


FIGURE 38.2 TYPICAL FRACTIONAL EFFICIENCY CURVE OF A CYCLONE

little effect on the operating performance of a cyclone. The major problem attributed to cyclone deficiency is normal wear and abrasion. Particles can be abrasive and actually wear through the shell of a cyclone. The enforcement official should observe the cyclone in its entirety for rust and leaks in the duct work and cyclone shell.

It is unlikely that cyclones will have air pollution monitoring instrumentation associated with them. At best, a manometer may indicate the pressure drop across the unit. If the manometer is available the enforcement official should record this pressure drop for future comparisons. A lower pressure drop noticed from visit to visit may indicate that the cyclone performance is deteriorating. For cyclones which have outlets to the atmosphere, the enforcement official should note the plume opacity. Finally, the enforcement official should ask what schedule is used to remove the collected particulate from the cyclone hopper.

PART VII

FIELD ENFORCEMENT EQUIPMENT

The enforcement official is expected to be able to perform some direct and simple field tests and measurements. These tests should indicate gaseous volumetric flow rates and pollutant concentrations. Particulates, sulfur dioxide, carbon monoxide, and fluorides are of special interest. It is anticipated that other pollutants may become subjects of interest from time to time.

The purpose of the enforcement official's field testing is to determine the need for complete source-emission testing in accordance with rigorous testing procedures. The simple tests performed by the enforcement official have inherent limitations and provide only an estimate of emission rates. Most of the information sought by the enforcement official will be available from plant operating records and instruments and therefore it is believed that direct field tests for estimating emission rates seldom will be required.

Source testing considerations must include the adverse field conditions under which the field tests are to be performed. These include high temperatures, presence of noxious gases and, possibly, poor accessibility.

The enforcement official's field testing equipment inventory needs to include:

1. A pitot tube, inclined manometer, and high and low temperature thermometers for gaseous emission volumetric flow rate determination,

2. A stack particulate sampling assembly that is to include a probe, a particulate filter, a flow meter, and a pump,
3. A kit of direct-reading colorimetric indicators primarily for the concentration determination of sulfur dioxide, carbon monoxide and hydrogen fluoride.

Gaseous emission volumetric flow rates can be obtained by the direct measurement of the average flow rate by pitot tube. The product of the average gas velocity and the cross-sectional area of the stack at the place of measurement gives the gas flow rate.

The pitot tube is a simple probe that is inserted in the stack. It permits the direct reading of the velocity head of the flowing gas stream at the tip of the pitot tube on an inclined manometer (Figure VII-1).

A simple mathematical relationship correlates velocity head to gas velocity. This relationship is defined for gases of density equal to air at one atmosphere by:

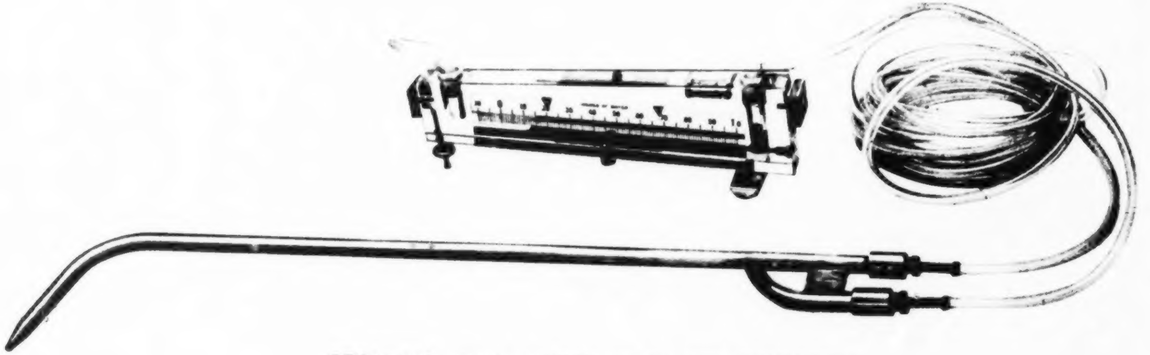
$$V_{av} = 2.90 \sqrt{\Delta h\ T}$$

where: V_{av} = gas velocity, fps

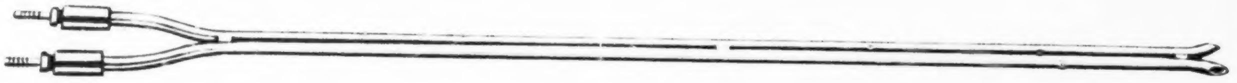
Δh = velocity head, in. H_2O

T = gas temperature, ^{o}R ($^{o}F + 460$)

A correction factor (normally 0.8) must be introduced into the equation for a type-S pitot tube because it slightly overstates the velocity, whereas the standard type pitot tube requires no correction. The average stack gas velocity is determined by measuring the velocity in the stack at several places and then obtaining the arithmetical average velocity.



STANDARD TYPE PITOT TUBE AND MANOMETER



S TYPE PITOT TUBE

FIGURE VII-1 PITOT TUBE AND MANOMETER

Weight concentration determination of particulate matter in the gaseous effluent requires the withdrawal of a known volume of gaseous effluent from the stack and determining the quantity of particulates in the effluent sample taken by removing the particulates by filtration and weighing the collected particulates. The net weight gain of the filter is the weight of the particulate strained from the effluent sample taken. The particulate weight concentration of the effluent is obtained by dividing the weight of the particulates collected by the volume of gas sampled, corrected to standard temperature and pressure. The usual unit of weight concentration is grains per standard cubic foot (gr/scf).

The desired goal is to obtain a representative average effluent particulate concentration. In order to achieve this aim as closely as possible without conducting rigorous tests under isokinetic conditions, the sample size should be at least 10 to 15 cf collected at an approximate rate of 1 scfm.

The sampling train is used for particulate concentration determination. It consists of a probe, housing the sampling nozzle and particulate filter, a flow meter and a pump. Figure VII-2 shows a Joy Manufacturing Co. filter holding assembly, including the probe. It is desired that the meter and air mover connected to the probe be lightweight, durable, and compact. For example, an air moving unit, the RAC Midget Air Sampler, manufactured by the Research Appliance Company, shown in Figure VII-3, is well suited for this purpose.

After determining the particulate loading (weight concentration) and the average velocity, it is possible to determine the mass emission rate in terms of lbs/hr or tons/day. Temperature pressure, cross-sectional

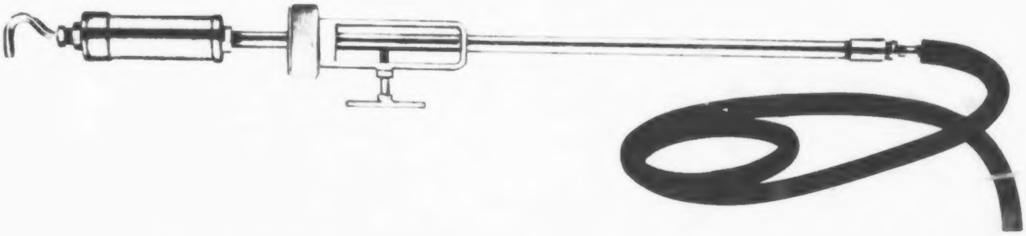


FIGURE VII-2 FILTER HOLDER ASSEMBLY AND PROBE

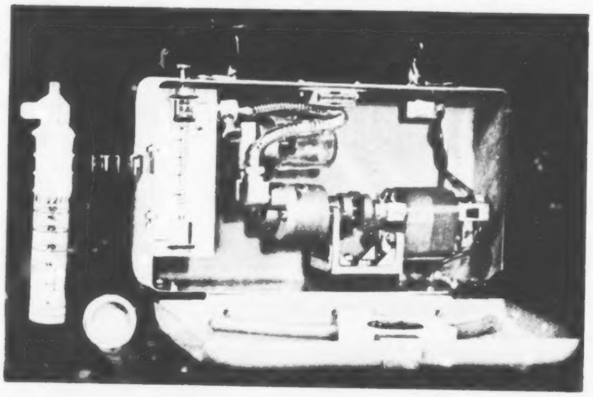


FIGURE VII-3 MIDGET AIR SAMPLER

area, and the proportion by volume of water vapor in the gas are also required. The temperature, pressure, and cross-sectional area are easily obtained by simple methodology. The proportion by volume of water vapor (B_{wo}) is more difficult to obtain. Hence, in some cases such as for a dry gas or where accuracy is not of great importance, the term B_{wo} can be taken as zero, thus simplifying the equation.

Mass emission rate equation:

$$Q = 60\,(1 - B_{wo})\,V_{av}\,A \left(\frac{T_{std}}{T_{av}}\right) \left(\frac{P_{av}}{P_{std}}\right)$$

where:

Q = Volumetric flow rate, scfm

B_{wo} = Proportion by volume of water vapor in the gas stream

V_{av} = Velocity Average, fps

A = Cross-sectional area of stack at test point, sq ft

T_{std} = Standard temperature, 530°R

T_{av} = Average temperature of stack gases, °R

P_{av} = Average pressure of stack gases, in. Hg

P_{std} = Standard pressure, 29.92 in. Hg

All values should be measured at the test port.

$$Q(\text{scfm}) \times \text{particulate loading (gr/scf)} \times 0.0086 \left(\frac{\text{min./lb}}{\text{hr/gr}}\right) =$$

Mass emission rate (lb/hr)

$$\text{Mass emission rate (lb/hr)} \times 0.012 \left(\frac{\text{ton/hr}}{\text{lb/day}}\right) = \text{Mass emission rate (ton/day)}$$

Effluent gaseous pollutant concentrations, such as carbon monoxide, sulfur dioxide and hydrogen fluoride, can be conveniently estimated by direct reading colorimetric indicators. The most common indicators are the solid chemical-in-glass indicator tubes. The underlying principle of these direct reading indicators is a selective chemical reaction between the chemical reagent in the tube and the pollutant of interest (different tubes for different pollutants) that produces a color change. The resulting color change can be directly correlated to the concentration of pollutant causing the color change by comparing either the color shade to standardized color-concentration correlation charts or the length of the colored tube to a calibration curve. The concentration is read in parts per million (ppm). The use of detecting tubes is extremely simple. The tubes are placed, after breaking off the sealed ends, in holders provided by the manufacturer which are fitted with a calibrated squeeze bulb or piston pump. The recommended volume of gaseous sample is then drawn through the tube at a low rate. For a few gases, a variable volume of sample is drawn through the tube until the first visible discoloration is noted. When sampling hot gases, cooling the sample is essential because of distortions introduced at high temperatures into calibration and gas volumes.

Indicator-tube gas analysis is very rapid, convenient, and inexpensive. The best accuracy that can be expected from indicator tubes is on the order of plus or minus 20 percent.

Various detector tubes are available to measure SO_2, CO, H_2S, HF, NO_2, O_3, etc. Although the detector tubes are not accurate, they are suitable for making an estimate of the gases by an inspector.

Opacity is an index of particulate emission and it is assumed that the enforcement official will be a certified smoke reader.

PART VIII

FIELD ENFORCEMENT PROCEDURE

PART VIII

FIELD ENFORCEMENT PROCEDURE

The type of air pollution regulation that has been adopted for these primary metallurgical operations include codes which set a maximum allowable particulate emission rate based on process weight rate, codes which restrict total sulfur emission as a function of sulfur (in ore) feed rate, and codes which regulate the mass emission rate of fluorides. Other types of air pollution regulations also apply to these primary metallurgical operations. Almost all agencies will have visible emission regulations which are applicable to these processes. A few state agencies also have a concentration type regulation for these industries independent of process weight rate.

From the types of air pollution codes that have been developed for these industries, it might be expected that the only measurement for determining compliance with the codes would be source sampling. The source sampling results could provide engineers with the exact emission levels of any pollutant and any operation; however, source testing is quite expensive, completion time is lengthy, and involves prior scheduling before testing. Any of these three criteria can become a deterrent for local air pollution control agencies in their enforcement of air pollution codes. The field enforcement procedures that have been developed for each of the metallurgical operations in this manual take these factors into consideration and attempt to minimize the amount of source testing needed for determining whether or not a source is in compliance with the existing codes. In order to meet the objectives of the Clean Air Act of 1970, many sources need to be controlled all of the time, not only when the air pollution official arrives on plant for a visit. The procedures that have been developed in each of these chapters will allow the enforcement official to make periodic checks at selected sources, and from the process operating parameters and air pollution control variables, assess whether or not a source is in compliance. It has provided guidelines for the enforcement official to determine whether or not the process is operating correctly and has identified what variations in operating circumstances affect air pollution emissions.

In order to develop a viable field enforcement procedure, a control official must first establish baseline conditions for each of the operations in his jurisdiction. The baseline conditions must include the stack sampling data which relates the process operating conditions during the stack test to air pollution control equipment parameters (eg., spark rate, pressure drop, flow rate, etc.). An enforcement official who makes periodic visits to certain plants must know what relationship exists between the source test results and the operating circumstances at the time of the test. If the enforcement official returns to the plant at a later date and finds some deviation in the operating variables (i.e., a higher production rate or lower pressure drop on scrubber), he can expect some increase or decrease in atmospheric emissions. For example, if a pressure drop across the venturi scrubber of 60 in. wg provided an atmospheric emission rate of 2 lbs/hr from a process feed rate of 500 tons/hr, a subsequent pressure drop of 35 in. wg would likely result in a several-fold increase in particulate emissions to the atmosphere. Some operating variables are not important at all as far as the air pollution control official is concerned. In these chapters it has been noted which variables affect and which variables do not affect air pollution emissions.

The enforcement official can use the worksheets for establishing the baseline conditions. A special worksheet should be identified as the baseline condition. On subsequent visits to the plant, the enforcement official will take along the worksheets for a particular metal operation of his concern and fill out the worksheet as he conducts his tour of a plant. The enforcement official should then compare the operating variables of his most recent visit with the baseline conditions and identify any changes which have occurred which might affect air pollution emissions. It should be pointed out that published emission factors were based on industry-wide surveys and cannot be applied to one specific source. At best, the emission factors indicate the magnitude of selected emission levels for the metallurgical operations.

For establishing baseline conditions of emission levels or any metallurgical operation, an air pollution control agency must have certain general information relative to the plant. This will include the name of the plant operator and specifically the personnel to be contacted when an inspection is required. The general information would include these data: plant address, phone number, and visiting procedures including visitor's passes and security clearances. Many control agencies will have an air pollution permit system. As part of the permit system, enforcement officials have requested plant layout and blueprints for all operations which emit pollutants into the atmosphere. The blueprints and design specifications for the machinery and air pollution control devices are important to the enforcement official in assessing design operating conditions. If process flow sheets are available, this background data will also be helpful and should be incorporated in the field enforcement file. Information on the process equipment or machinery should include a general description of the unit, design specifications, meter readings, capacity and the operating time. The description of the process should identify whether this is a batch or continuous operation.

The information on air pollution abatement equipment would include a general description of the device, the design specification, meter readings, and collection efficiency. Design parameters such as the gas flow rate, temperature, pressure drop, water flow rate, and spark rate are critical factors that should be identified and kept on record.

At this stage of air pollution control in the United States, plant officials will have made air pollution emissions tests on nearly every one of their processes and/or stacks. Some of the testing information will have already been submitted to the agency in applying for an air pollution permit. The stack sampling data is of strategic importance to the enforcement official and inspector who will routinely visit these plants. Plant operating data are routinely collected with stack tests. Ask for them. Parameters like pressure drop, spark rate, inlet temperature, water flow rate, and opacity will help the enforcement official in his routine inspection. Many plants will use stack opacity meters as a means of monitoring air pollution control device performance. Enforcement officials will be able to use the same opacity meters and continuous records for assessing the operability and emission levels. If stack tests are made on those operations which have opacity meters, and if parallel readings were taken, the enforcement official will have some idea of emission load when he visits the plant.

Each time an enforcement official visits a plant, he will fill out the Inspector's Worksheet. That information will be kept as a continuous record on emissions and operating parameters for given certain operations of a plant. Also included in the field data file would be the records of complaints that have been received relative to a specific source. These complaints might precipitate plant visits. If the plant visits are successful and there are no complaints, then perhaps a frequency of once-per-year is adequate. If the plant is frequently in violation and complaints exist, more frequent inspections would be necessary.

The U. S. Environmental Protection Agency has developed a computerized system entitled, "Enforcement Management System Users Guide, APPD 1237." The bulk of the information included in the field enforcement file may be applied to this computerized system for an up-to-date and speedy method to retrieve data on selected sources.

Personnel requirements for air pollution control agencies will vary depending upon the type of sources in its jurisdiction. To inspect primary metals installations and maintain records of plant activities would require an individual with an engineering background. Many of the calculations that have been included in this manual are relatively simple and could be completed by an individual with several years of college engineering. Direct working experience in any of the metals operations would be a tremendous asset for carrying out the objectives of an enforcement program.